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AN ANALYTICAL SERIES

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The Chromium Industry of the U.S.S.R.

By Vasilii V. Strishkov and Walter G. Steblez

BUREAU OF MINES ★ UNITED STATES DEPARTMENT OF THE INTERIOR

I 28.156:

Mineral Issues

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By Vasilii V. Strishkov and Walter G. Steblez

UNITED STATES DEPARTMENT OF THE INTERIOR
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As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environment and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in island territories under U.S. administration.

Library of Congress Cataloging-in-Publication Data

Strishkov, Vasilii V.
The chromium industry of the U.S.S.R.

(Mineral issues)
Includes bibliographies.
Supt. of Docs. no.: I 28.156:C46

1. Chromium industry—Soviet Union. I. Stebler, Walter G. II. Title. III. Series.

HD9539.C242S857 1985 338.2'74643'0947 85-600184

PREFACE

With the third largest chromite reserves in the world, the U.S.S.R. has been among the world's leading producers and exporters of chromite, and is likely to remain a major producer. Interest in the Soviet chromium industry has been intensified by both the decline of the country's production growth rate and of the quantitative level of exports.

A study of the U.S.S.R. chromium industry (mining, concentration, smelting, trade, and consumption) and a survey of the country's chromium reserve situation, are of great significance for evaluating changes in the U.S.S.R.'s long-term foreign trade and world mineral supplier status. A description of the historical development of the U.S.S.R.'s chromium industry presents a comprehensive picture in respect to reserves, technology, and statistics for production, trade, and consumption.

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

h	hour	mm	millimeter
ha	hectare	m^3	cubic meter
km	kilometer	mt	metric ton
km^2	square kilometer	mt/d	metric ton per day
kW	kilowatt	mt/yr	metric ton per year
m	meter	yr	year

THE CHROMIUM INDUSTRY OF THE U.S.S.R

By Vasilii V. Strishkov[1] and Walter G. Steblez[2]

ABSTRACT

As a major world producer and exporter of chromite, the U.S.S.R. possesses sufficient chromite reserves to meet its long-term requirements. Recent declines in Soviet chromite production growth and in exports have raised the issue of the U.S.S.R.'s prospective future as a world supplier. This Bureau of Mines report provides a description of the salient characteristics of the U.S.S.R. chromium industry including the raw material base, mining and processing facilities, foreign trade, and policies and programs controlling its operations, and outlook for the future.

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SUMMARY

Currently, the U.S.S.R. is ranked as the first chromite producer and second exporter in the world. Its reported exploitable reserves rank third among those of world producers. As with all other economic industrial activity in the U.S.S.R., major goals of the chromium industry are centrally planned. Both annual and 5-yr goals are developed by the State Planning Committee and are approved by the U.S.S.R. Supreme Soviet. Plans concerning chromite production and processing are directed to the U.S.S.R. Ministry of Ferrous Metallurgy, which then assigns detailed tasks to individual mines and plants. Although these plans technically carry the force of law, actual completion on schedule and to desired levels of accomplishment is often not met. The main rationale of Soviet chromite mining and processing operations is to assure maximum self-sufficiency on a centrally planned basis. Assigned production tasks often carry political considerations as well as commercial ones with the former taking precedence.

All presently known significant explored, exploitable reserves of chromite in the U.S.S.R. are within ultramafic massifs in the Ural Mountains in both the Kazakh S.S.R. and the Russian S.F.S.R. The most important of these reserves are located in the Kazakh S.S.R. The total estimated explored, exploitable reserves in place (in Soviet classification categories A + B + C_1) as of January 1, 1984, were 229 million mt of chromite with a Cr_2O_3 content of not less than 32%, and a Cr_2O_3-FeO ratio of not less than 2.5:1.

Soviet chromite production levels fluctuated as a result of available ore supplies, market demand, and political-military problems from the inception of production until 1938 (the last year of officially published quantitative production data), whether measured in terms of crude ore or marketable product. From 1938 through 1974, output levels of both trended constantly upward on the basis of reported growth rates. In 1975, production of marketable chromite dropped and then recovered somewhat, but has not yet regained the 1974 level. A nearly corresponding decline in crude ore output was noted beginning in 1975. These declines resulted from depletion of higher grade ores amenable to surface mining.

Exports similarly varied according to supply, market conditions, and government policy from Czarist times through the start of World War II. There was an increase in shipments in the late 1940's, a drop in the early 1950's, and a virtually constant increase from 1954 to a peak in 1973. This activity was followed by a 3-yr fluctuation in the 1- to 1.2-million-mt range and a significant downturn in 1977, followed by generally downturning levels through 1983.

Soviet equipment used in the chromium industry is standardized, and, in broadest terms, similar to that used in market economy countries. However, it is generally less modern in design and of poorer quality. Shortages of spare parts and the poor quality of equipment such as drills, excavators, and dump trucks are largely responsible for extended periods of downtime at most operations, and contribute to inefficiency.

Although the number of production workers at the main production facilities for the period 1970 to 1977 increased 1.5 times, production of marketable chromite rose by only 2.9%. The drop in the U.S.S.R. production growth rate led to a noticeable drop in exports in 1977, which continued through 1982.

Increases in Soviet chromite production and expanded ferrochromium capacities in the future would be long-term projects. It is likely that eventual exports of ferrochromium would increase while those of chromite would decline owing to increasing higher vertical integration of the industry. There would probably not be a significant impact on the world market from increased Soviet production of crude chromite and ferrochromium because of increased needs, both domestically and in Council of Mutual Economic Assistance (CMEA) countries. Moreover, because of high energy expenditure for ferrochromium production, and the higher transport costs for chromite, Western industrial nations have been relying to an increasing extent on the import of ferrochromium in lieu of chromite.

INTRODUCTION

The aim of this Bureau of Mines report is to provide a detailed description of the Soviet chromium industry with information on the production and trade of chromite, chromium alloys, and other chromium products, and with reference to historical development and future trends. Official open-source literature on this industry has been largely lacking since 1937 in regard to the production of chromite and ferrochromium, and since 1976 in regard to the export of ferrochromium.

After an extensive study of the available Soviet literature, methodologies were developed to compute and estimate production and trade. In the case of chromite, official production data were published until the late 1930's. Subsequently, the U.S.S.R. published comprehensive growth rate indexes for both run-of-mine and marketable chromite output at 5-yr intervals for the major chromite producing areas in the country. Actual national production results in the early 1980's were also published, which allowed the Bureau to compute production for the given years and interpolate for intervening periods. Furthermore, chromite trade data are officially published each year.

The case of ferrochromium was more complex. Official production data have been unavailable since before World War II. Computations and estimates of production were made on the basis of published percentage growth rates using 1940, in which reasonably good data are available, as a base year. These growth rates permitted the calculation of ferrochromium production for a 3-yr period (1946, 1950, and 1955) during the 1940-55 period, and interpolation (guided by available metallurgical chromite consumption data) for intervening periods. After 1955, production was largely estimated on the basis of available capacities and the actual availability of metallurgical grade chromium ore and concentrate for domestic consumption and export. Officially published general ferroalloy growth rate data were also used. After 1976, ferrochromium trade was reconstructed through backwards trade and linear analysis of ruble-metric ton ratios from previous periods through 1983.

CHAPTER 1.—DEFINITION OF TERMS AND WORLD SIGNIFICANCE OF THE SOVIET CHROMITE INDUSTRY

TERMS

Chromite is the only commercial chromium mineral, and it contains varying percentages of the oxides of chromium, iron, aluminum, magnesium, and minor elements. The ore has been traditionally classified into three general grades (metallurgical, refractory, and chemical), depending largely on chromium content, on chromium-iron ratios, and on impurities.

It should be noted that with regard to the chromium-iron ratio, standard Soviet practice is to express this in terms of the ratio of chromic oxide to ferrous oxide (Cr_2O_3:FeO), which is in contrast to the western practice of expressing it in terms of elemental chromium to elemental iron (Cr:Fe). Throughout this report, the Soviet reporting practice has been followed, rather than providing approximate figures calculated by the Bureau to western standards. Users desiring to convert the data to the western practice may do so by multiplying the figure provided for the chromium part of the ratio by a factor of 0.88, thus a Cr_2O_3 – FeO ratio of 3:1 becomes a Cr – Fe ratio of 2.64:1.

Soviet specifications for metallurgical-grade chromite produced in the Donskoy complex require that it shall be in lump form and have a chromite oxide content of 45% to 52% and a Cr_2O_3 – FeO ratio of 2.7:1 to 3.2:1. Detailed specifications are given by grade in table 1.

Table 1.—Soviet specifications for Donskoy complex metallurgical-grade chromites (*14*)

	DX-1	DX-2	DX-3
Cr_2O_3, minimum ..... % ..	52	50	45
SiO_2, maximum ..... % ..	5	8	10
P, maximum ..... % ..	0.03	0.03	0.03
Cr_2O_3-FeO ratio, minimum ..	3.2:1	3.0:1	2.7:1
Lump size ..... mm ..	10-300	0-300	0-300
0 to 10 mm, maximum .. % ..	15	0	0

Soviet standards specify that Donskoy complex chromite for the refactory industry should contain 32% or more Cr_2O_3, a maximum of 7% SiO_2, and a maximum of 1.3% CaO (table 2). The alumina-rich chromite (17.5%-18.94% Al_2O_3) of the Saranov deposits should contain a minimum of 33% Cr_2O_3, a maximum of 9% SiO_2, and a maximum of 1.5% CaO according to Soviet standards (*2*).[1]

Table 2.—Soviet specifications for Donskoy complex refractory-grade chromites (*1*)

	Run of mine	Highest quality
Content, %:		
Cr_2O_3, not less than	32	45
SiO_2, not more than	7	7
CaO, not more than	1.3	1
Cr_2O_3-FeO ratio, more than	2.5:1	2.5:1
Lump size, not less than .. mm ..	3	3

[1]Italic numbers in parentheses refer to items in the list of references at the end of this chapter.

Although official standards for the chemical industry lean ores are not available, ores with 36% Cr_2O_3 are used in actual practice, preferably fine-sized ores requiring no additional grinding.

The Soviet Union has somewhat different standards for exported chromite than those stated for production. Export chromite from the Donskoy complex of Kazakhstan should have the following chemical analysis: Cr_2O_3—48% (basic), minimum 47%; SiO_2—maximum 7%; P—maximum 0.008%; S—maximum 0.05%; and Cr_2O_3 – FeO ratio of 3:1 (basic), minimum is 2.9:1. The chromite exported from the Saranov deposits of the Russian S.F.S.R. contain not less than 36% Cr_2O_3 (*16*).

It should be noted that chromite is little suitable for industrial purpose in its pure form, as the Cr_2O_3 – FeO ratio is only 2.1:1, while for smelting of standard ferrochromium it should be not less than 2.5:1.

Currently, marketable metallurgical chromite ore and concentrates from the Donskoy complex in Kazakhstan, which produces about 94% of the Soviet total, includes materials with a Cr_2O_3 content of at least 45%, and a maximum lump size of 300 mm (*11*). Generally, Donskoy ores in place are divided into three grades: rich ore with a Cr_2O_3 content of 45% and more; lean ore with 30% to 45% Cr_2O_3, and poor ore with Cr_2O_3 content below 30% (*12*). The GOST (State Standard) classified the chromite and concentrates produced in the U.S.S.R. into 22 grades (*3*). To meet these grade requirements, measures for the selective extraction and blending of ore from the various open pits were necessary, particularly in the working of small ore bodies.

The principal differences in definitions between those used in this report and those in standard Bureau of Mines practice is in the classification of reserves. According to the Soviet classification scheme approved in 1982 (*13*), deposits of all solid minerals are classified under two cross-imposed systems, one relating to the economic viability of the material in question, and the other relating to the reliability of the information on the quantity of material in place. Under the first system, the Soviets separate deposits into one of two categories, "balansovyye" or "zabalansovyye." The former word literally translated means balance, this term referring to the fact that materials so classified are included in studies relating to mineral reserves in place that are suitable for exploitation. This balansovyye material, in effect is that which currently is regarded as viable for economic development or exploitable. The other category term, zabalansovyye, translates literally to beyond balance, the term implying that materials so classified are not regarded as suitable for economic exploitation at the present. For chromium, material in place must have a minimum Cr_2O_3 content of 32% and a Cr_2O_3-FeO ratio of not less than 2.5:1 to qualify for the balansovyye category.

The second classification system relating to the reliability of information on the quantity of material in place assigns each occurrence to one of seven categories, the traditional A, B, C_1, and C_2, and P_1, P_2, and P_3, prognoznyye resursy (prognoses resources). The first four categories are regarded as reserves by the Soviets, but some materials reported in each of these classes may not correspond to the western concept of reserves (material economically exploitable under present market prices with existing technology); that is, some of the materials in A, B, C_1, or C_2 categories may be regarded

as zabalansovyye. The final three categories, P_1, P_2, and P_3, together with zabalansovyye material from categories A, B, C_1, and C_2, correspond very roughly to the western term "resources."

Mining and construction of mining enterprises and the appropriate capital investment are authorized on the basis of the economic (balansovyye) reserves in place in categories $A+B+C_1$, which must be in prescribed ratios. Reserves in the C_2 category are also taken into account in project planning for mining enterprises, to provide a general perspective of the development, but they do not constitute a justification for project planning.

All of these four categories (A, B, C_1, and C_2) are based on the data obtained on an exploration grid of prescribed density (or by its equivalent) and on certain types of chemical and other tests according to regulations. Density of the grid, in each of the reserves categories, is different for different kinds of ore and for five different types of ore bodies, depending on geological formation.

According to Soviet classification, the reserves and resources of solid mineral raw materials in place are divided into explored (razvedannyye)—$A+B+C_1$ categories and prospective (perspektivnyye)—C_2 categories. The categories P_1, P_2, and P_3 are prognoses resources (prognoznyye ressursy). The appropriate specifications for each of these four categories are as follows:

A—The reserves in place are known in detail. The ore body boundaries are outlined by trenching, exploratory boreholes, or exploratory workings; the depositional environment, the proportion of different commercial grades of the ore, and the hydrogeologic conditions of the exploitations are ascertained; and quality and technological properties of the ore are ascertained in detail, assuring the reliability of the projected beneficiation and production operations.

B—The reserves in place are explored. The ore bodies are outlined by exploratory workings or by exploratory boreholes; the depositional environment is known; types and industrial grades of the ore are ascertained but without details of their distribution; quality and technological properties of the ore are known sufficiently well to assure the correct choice of the system for its beneficiation; and general conditions of the exploitation and the hydrogeologic environment, as a whole, are known in fair detail.

C_1—The reserves in place are estimated by a sparse grid of exploratory boreholes or exploratory workings. This category also includes reserves adjoining the boundaries of the A and B categories of ore as well as the reserves of the very difficult deposits in which the distribution of the values or of mineral cannot be ascertained even by a dense exploratory grid; quality, types, industrial grades, and technology of the beneficiation are ascertained tentatively, by the means of analyses and of laboratory tests and by analogy with known deposits of the same type; and general conditions of the exploitation and a general hydrogeological environmental of the deposit known tentatively.

C_2—The reserves in place adjoining the explored reserves of A plus B plus C_1 categories and reserves indicated by geologic and geophysical evidence confirmed by boreholes.

Depending on the nature of deposits, various boring and excavation methods are used in the determination of ore reserves for all solid minerals in the Soviet Union. The major groups into which deposits are divided follow.

First Group Deposits.—Deposits are simple in form, and have large dimensions and uniform distribution of minerals (such as coal deposits, many deposits of iron ore, and disseminated copper deposits). The high category reserves of such deposits can be determined by boring with a normal density grid of boreholes. Excavation is used only for controlling the data of samples from boreholes and for taking bulk samples.

Second Group Deposits.—Large deposits of different and sometimes complicated forms, with uneven distribution of mineral content. A combination of both drilling and exploratory workings is required to determine ore reserves. With a normal grid of boreholes, only reserves of B category might be revealed by drilling. With close-spaced drilling, and control by exploratory workings, it is possible to establish reserves of A category.

Third Group Deposits.—Deposits of medium dimensions with irregular distribution of ore minerals, such as vein or dyke deposits. Reserves of A and B categories can be revealed only with the help of openings. Drilling alone can establish reserves only of C_1 category.

Fourth Group Deposits.—Deposits similar to group 3 but with smaller ore bodies of more complicated forms. It is impossible to establish category A reserves under a normal grid of openings. Exploratory openings and underground drilling are needed to determine ore reserves of category B.

Fifth Group Deposits.—Small pocket deposits of categories A and B, which could not be established by systematic prospecting. Only category C reserves can be established.

Virtually all chromite deposits are classified as falling in groups 3 through 5. The State Commission for Mineral Reserves [Gosudarstvennaya Kommissiya po Zapasam (G.K.Z.)] or, in the case of small projects, the Territorial Commission for Mineral Reserves [Territorial'naya Kommissiya po Zapasam (T.K.Z.)], of the Ministry of Geology of the U.S.S.R., certifies the reserves in question as adequate for planning purposes.

As previously noted, U.S. and Soviet categories of mineral reserves do not entirely coincide. U.S. measured, indicated, and inferred categories cannot be precisely matched to the Soviet A, B, C_1, and C_2 categories. Evaluations of Soviet mineral reserves in U.S terms require an understanding of the Soviet usage and its modifications. For purposes of a general understanding of the size of Soviet reserves, the Soviet category A may be taken as equivalent to the U.S. category of measured ore, and category B corresponds fairly well to the U.S. category of indicated ore. Indicated ore is ore in place that is computed from information similar to the measured category, but of a lesser degree of detail or certainty.

The U.S. category of inferred ore is based on geologic evidence, with or without some supporting measurements. This category differs most from the corresponding Soviet categories—C_1 and C_2. The Soviet categories both require that geologic and geophysical evidence be confirmed by boreholes. Since the early 1960's, the Soviets have not reported categories A, B, and C_1 separately, considering them all adequate for planning purposes. These are referred to as razvedannye, or explored. It should now be noted that it is possible that some chromite may be classified as A, B, or C, and yet fall within the zabalansovyye (or uneconomic category). This is not common, but it can occur.

Finally, resources, rather than reserves of one degree or another of assurance, are referred to as prognoznyye ressursy, or prognosticated resources, and are placed in three categories, P_1, P_2, and P_3, of diminishing (or vanishing) assurance. In the United States, these are all in the category of inferred resources.

A simplified chart of reserve classification categories of Soviet chromite is presented in figure 1, which also shows the relationship of the reserve categories to materials produced, including both marketable output and losses, as well as to materials that cannot be recovered for technical reasons.

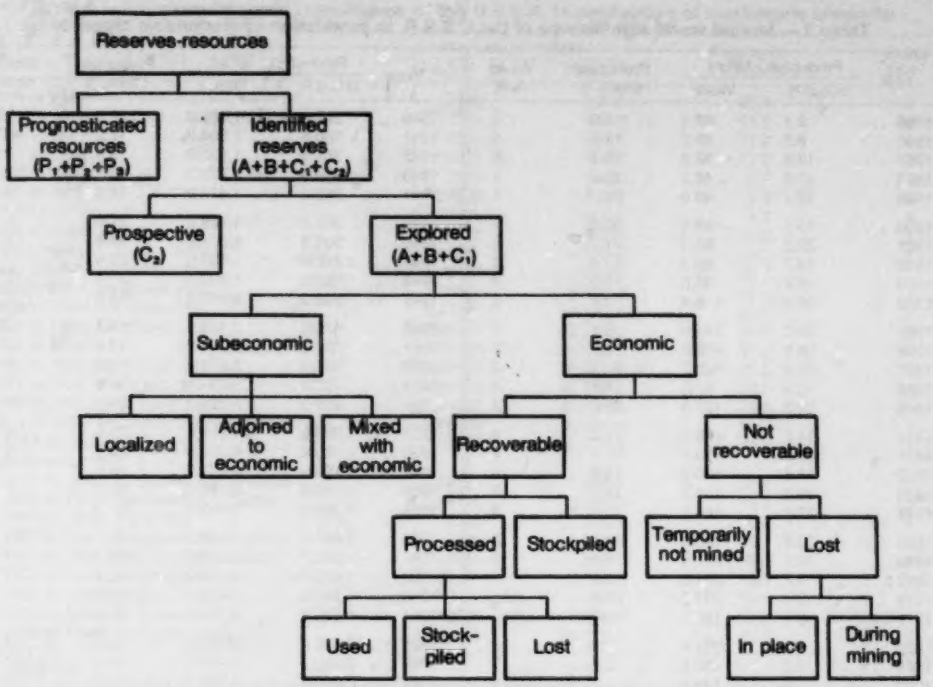

Figure 1.—Soviet reserve-resource classification for solid minerals.

WORLD AND NATIONAL SIGNIFICANCE

From the mid-1890's to the present, the U.S.S.R. and its political predecessor, Czarist Russia, has been a major factor in the world's supply of marketable chromite, accounting for nearly 31% of total world production during the 1895-83 period for which work data are available. During that period, it ranked first among world producers in 38 yr, including an unbroken period of 23 yr from 1954 to 1976 and the most recent 2-yr period, 1982-83. It ranked second in 24 more years, and third in 11 yr. The only period in this century that it has not ranked as a significant producer was 1918-23, when civil war disrupted most economic activities in the country.

With the reestablishment of private industry in the U.S.S.R., mining operations were resumed and production in 1925 again reached the prewar level with 30,000 mt representing 9.2% of the world production. Most of Soviet chromite output came from the small deposits of the Urals and only one-third of output was of metallurgical grades. Following discovery of rich Kempirsay chromite deposits in 1937, production of chromite in the U.S.S.R. increased from 186,000 mt in 1936 to 271,000 mt in 1941. By 1950 the mining of small deposits in the Urals had ceased and the total output was coming from the Kempirsay deposits in Kazakhstan and Saranov in the Urals. In the 1950-83 period, production, stimulated by both domestic and export demand, generally trended upward. In 1983, estimated production of crude chromite was 3.35 million mt, and that of marketable chromite was 2.94 million mt, or nearly 35% of total world output. Tables 3 and 4 show the Soviet production of marketable chromite, and its relation to world output for the 1895-1983 period.

The Soviet Union occupies a unique position in the world chromite situation. Although chromite is found throughout the world, commercially exploitable deposits are mainly located in regions remote from the centers of ultimate consumption. The U.S.S.R. is the only major industrialized state that possess extensive chromite reserves within its national boundaries. (The Republic of South Africa, with the world's largest reserves, although an industrialized country, is only a very modest final consumer of chromium.)

During the 1981-85 period, the U.S.S.R. planned to increase crude ore production by 400,000 mt, including a 14% growth in Kazakhstan. During the same period, it was planned to bring facilities on-stream with annual capacities of 2.9 million mt of crude chromite and 2 million mt of concentrate, but presumably these facilities in part will replace other operations.

With regard to its prominence in international chromite trade during the past decade, the Soviet Union, first-ranked for several years up to 1974, ranked second to the Republic of South Africa in exports in 1975, 1976, 1978, 1980, and 1981; third behind the Republic of South Africa and Albania in 1977, 1979, and 1982; and presumably ranked second or third in 1983.

From a high of 1,226,000 mt in 1973 exports fell to 561,000 mt in 1982, and 496,000 mt in 1983. Exports of ferrochromium have not increased to a level that would counterbalance the drop of chromite exports. High-grade ore for surface mining is approaching depletion and it is noteworthy that much less of this has been destined for the export markets, particularly those of market economy countries. During the 1979-83 period, East European members of the Council for Mutual Economic Assistance (CMEA), received over half of all Soviet chromite exports; Czechoslovakia and Poland were the principal recipients. Soviet export-to-production ratios (chromite and ferrochromium) and trends are given in table 5. In recent years, Soviet exports of chromite and concentrates to the West have been less than one-fourth of their 1970 total. For example, exports to the United States have dropped dras-

Table 3.—Annual world significance of the U.S.S.R. in production of marketable chromite

Year	Production,[1] 10^3 mt		Production share, %	World rank	Year	Production,[1] 10^3 mt		Production share, %	World rank
	U.S.S.R.	World				U.S.S.R.	World		
1895 ...	2.1	42.1	5.0	5	1940 ...	260.0	1,429.0	18.2	1
1896 ...	6.2	43.2	14.3	3	1941 ...	260.0	1,594.2	17.0	2
1897 ...	13.4	52.9	25.4	2	1942 ...	381.9	1,930.8	15.5	3
1898 ...	15.5	46.2	33.5	1	1943 ...	419.8	1,822.3	18.1	2
1899 ...	18.2	48.0	32.2	1	1944 ...	358.3	1,427.2	24.5	1
1900 ...	19.1	53.2	36.0	1	1945 ...	361.2	1,139.8	31.6	1
1901 ...	22.2	89.9	24.7	2	1946 ...	360.0	1,244.8	28.9	1
1902 ...	19.7	85.3	23.0	2	1947 ...	370.0	1,623.5	22.8	2
1903 ...	16.4	95.5	17.2	3	1948 ...	385.0	1,920.1	20.1	2
1904 ...	26.6	118.4	22.4	2	1949 ...	390.0	2,078.8	18.8	2
1905 ...	27.0	144.4	18.7	2	1950 ...	410.0	2,229.1	18.4	2
1906 ...	25.0	169.8	14.7	3	1951 ...	505.0	2,669.0	18.9	2
1907 ...	26.4	129.7	20.3	3	1952 ...	600.0	3,692.8	16.2	3
1908 ...	10.9	67.0	16.4	4	1953 ...	700.0	3,761.8	18.6	2
1909 ...	22.2	107.6	20.6	3	1954 ...	810.0	3,333.8	24.3	1
1910 ...	14.2	108.3	13.2	3	1955 ...	1,000.0	3,863.9	25.9	1
1911 ...	30.2	110.1	27.5	2	1956 ...	1,100.0	4,236.4	26.0	1
1912 ...	26.2	130.8	19.9	2	1957 ...	1,190.0	4,671.7	25.5	1
1913 ...	29.3	156.4	18.7	3	1958 ...	1,130.0	4,245.1	30.6	1
1914 ...	22.0	163.5	13.5	3	1959 ...	1,380.0	4,353.8	31.7	1
1915 ...	22.8	192.8	11.8	3	1960 ...	1,490.0	4,888.2	30.5	1
1916 ...	19.5	282.8	6.9	6	1961 ...	1,580.0	4,838.3	32.7	1
1917 ...	9.2	251.0	3.7	6	1962 ...	1,670.0	4,719.2	35.4	1
1918 ...	0	287.3	NAp	NAp	1963 ...	1,780.0	4,433.3	40.2	1
1919 ...	0	185.1	NAp	NAp	1964 ...	1,890.0	4,724.7	40.0	1
1920 ...	2.6	172.8	1.5	9	1965 ...	2,050.0	5,368.6	38.2	1
1921 ...	2.6	132.8	2.0	7	1966 ...	2,280.0	5,730.7	39.8	1
1922 ...	.9	139.0	.7	7	1967 ...	2,370.0	5,682.6	41.7	1
1923 ...	.9	203.1	.4	9	1968 ...	2,490.0	5,948.6	41.9	1
1924 ...	11.9	291.6	4.1	6	1969 ...	2,570.0	6,294.6	40.8	1
1925 ...	30.1	326.9	9.2	5	1970 ...	2,660.0	7,129.1	37.3	1
1926 ...	*30.4	363.2	8.4	5	1971 ...	2,750.0	7,510.5	36.6	1
1927 ...	*19.3	400.3	4.8	4	1972 ...	2,900.0	7,371.5	39.3	1
1928 ...	*25.5	447.6	5.7	6	1973 ...	3,000.0	8,014.0	37.4	1
1929 ...	52.9	635.2	8.3	4	1974 ...	3,040.0	8,315.7	36.6	1
1930 ...	82.0	574.2	14.3	2	1975 ...	2,860.0	9,154.9	31.2	1
1931 ...	87.0	402.9	21.6	1	1976 ...	2,620.0	8,967.8	29.2	1
1932 ...	64.2	297.5	21.6	2	1977 ...	2,720.0	10,296.6	26.4	2
1933 ...	117.7	416.7	28.2	1	1978 ...	2,810.0	9,923.9	28.3	2
1934 ...	115.0	613.1	18.8	2	1979 ...	2,990.0	10,351.9	28.9	2
1935 ...	175.0	782.7	22.4	1	1980 ...	2,900.0	10,247.1	28.3	2
1936 ...	*186.0	1,036.1	18.0	1	1981 ...	2,900.0	9,473.8	30.6	1
1937 ...	209.7	1,280.8	16.4	2	1982 ...	2,940.0	8,502.3	34.6	1
1938 ...	230.0	1,167.4	19.7	1	1983 ...	2,940.0	8,503.4	34.6	1
1939 ...	244.5	1,265.2	19.3	1					

*Estimated. NAp Not applicable. [1]Rounded.

Sources: U.S.S.R. data—1895-1910 (*18*); 1911-24 (*15*); 1929-31 (*17*); 1932-35 (*10*), 1937 (*8-9*), 1938-78 (*4*), 1979 (*5*), 1980 (*6*), 1981 (*7*).

NOTE.—World data were compiled from a wide variety of national sources and other materials in 1984 in an effort to provide comparable (marketable output) figures for all countries; detail and total will not correspond to those published in Bureau of Mines Minerals Yearbooks owing to revisions in individual country data (including those for the U.S.S.R.) in the effort to achieve comparability.

tically in the past 5 yr from 234,000 mt in 1979 to only 11,000 mt in 1982 and to nil in 1983.

There was a corresponding downturn in shipments to other non-CMEA countries, particularly after 1977. Shipments to Japan, France, Federal Republic of Germany, Italy, and Sweden all were significantly lower during the 1978-83 period than during the preceding 6-yr period. In contrast, shipments to CMEA countries and to Yugoslavia during the most recent 5-yr period were, in aggregate, very near the level of the 1972-77 period.

Although chromite occurs in many regions of the U.S.S.R., virtually the entire annual output is at present extracted from the Kempsirsay ultrabasic massifs in Kazakhstan. The Donskoy complex in Kazakhstan provided 94% to 96% of recent output; the balance is obtained from the Saranov Mine in the mid-Ural region.

With an estimated explored, exploitable reserve in place (in Soviet categories $A+B+C_1$) of over 229 million mt of chromite, the U.S.S.R. ranks second in reserves after the Republic of South Africa, and ahead of Zimbabwe, the Philippines, India, and Albania. About 94% of Soviet exploitable reserves are situated in Kazakhstan with the balance in the Urals. There are over 20 deposits in Aktyubinsk Oblast' in Western Kazakhstan of which Molodezhnoye, Millionnoye, and Almaz-Zhemchuzhina are the largest.

In 1983, the Soviet Union ranked second among world producers of ferrochromium including ferrochromium-silicon and first among European producers. Electric furnace plants

Table 4.—Summary of world significance of the U.S.S.R. in production of marketable chromite

Period	Production,[1] 10^3 mt		Production share, %	World rank
	U.S.S.R.	World		
1895 to 1901	74.6	285.6	26.1	2
1901 to 1906	111.9	533.5	21.0	3
1906 to 1911	98.8	582.4	17.0	2
1911 to 1916	130.5	755.7	17.3	3
1916 to 1921	31.3	1,163.0	2.7	7
1921 to 1926	46.5	1,093.2	4.3	6
1926 to 1931	210.1	2,420.6	8.7	4
1931 to 1936	558.9	2,512.9	22.2	1
1936 to 1941	1,130.8	6,178.5	18.3	1
1941 to 1946, World War II	1,781.2	7,914.2	20.4	1
1946 to 1951, 4th Soviet plan	1,915.0	9,096.3	21.1	1
1951 to 1956, 5th Soviet plan	2,615.0	17,321.4	20.9	1
1956 to 1961, 6th Soviet plan[2]	6,560.0	22,395.7	28.8	1
1961 to 1966[2]	8,970.0	24,048.1	37.2	1
1966 to 1971, 8th Soviet plan	12,370.0	30,785.5	40.2	1
1971 to 1976, 9th Soviet plan	14,550.0	40,366.6	36.0	1
1976 to 1981, 10th Soviet plan	14,040.0	49,787.3	28.2	1
1980 to 1984, 1st 3 yr of 11th Soviet plan	8,780.0	26,479.4	33.2	2
Total or average[3]	74,890.5	243,771.5	30.7	1
Significant periods:				
1895 to 1914, Pre-World War I Russia	392.9	1,964.3	20.0	2
1895 to 1917, Pre-Revolution Russia	444.4	2,690.9	16.5	3
1914 to 1917, World War I	73.5	890.1	8.3	4
1917 to 1921, War communism period	14.5	1,013.0	1.4	9
1921 to 1928, New Economic Policy	96.1	1,856.7	5.2	5
1928 to 1933, 1st Soviet plan	311.7	2,357.5	13.2	2
1933 to 1938, 2d Soviet plan	804.0	4,129.4	19.5	1
1938 to 1942, 3d Soviet plan[4]	1,398.6	7,386.6	17.7	1
1959 to 1966, 7th Soviet plan[2]	11,840.0	33,326.1	35.5	1

[1]Rounded.
[2]For policy reasons, the 6th plan was terminated early (at end of 1958) and was in part replaced by the 7th plan (7-yr duration).
[3]Data may not add to totals shown owing to independent rounding.
[4]Terminated early because of dislocations resulting from World War II.

Table 5.—U.S.S.R. export-to-production ratios for chromite and ferrochromium

Year	Marketable chromite, 10^3 mt		Export share of production, %	Ferrochromium, 10^3 mt		Export share of production, %
	Production	Export		Production	Export	
1957	1,190	259	21.8	113	16.9	15.0
1958	1,300	215	16.5	125	20.0	16.0
1959	1,380	272	19.7	138	18.7	13.6
1960	1,490	427	28.7	140	22.2	15.9
1961	1,580	438	27.7	148	21.7	14.7
1962	1,670	472	28.3	162	16.0	9.9
1963	1,780	567	31.9	180	14.1	7.8
1964	1,890	663	35.1	195	15.4	7.9
1965	2,050	748	36.5	200	24.8	12.4
1966	2,280	920	40.4	220	29.8	13.5
1967	2,370	1,030	43.5	240	31.0	12.9
1968	2,490	1,048	42.1	257	33.3	13.0
1969	2,570	1,144	44.5	268	37.8	14.1
1970	2,660	1,200	45.1	280	44.8	16.0
1971	2,750	1,054	38.3	307	42.3	13.8
1972	2,900	1,065	36.7	314	48.7	15.5
1973	3,000	1,226	40.9	324	46.4	14.4
1974	3,040	1,139	37.5	332	46.4	14.0
1975	2,860	1,171	40.9	333	44.6	13.4
1976	2,620	975	37.2	335	48.8	14.6
1977	2,720	677	24.8	337	44.4	13.2
1978	2,810	738	26.3	339	44.8	13.2
1979	2,990	775	25.9	370	35.7	9.6
1980	2,900	567	19.6	390	41.6	10.7
1981	2,900	567	19.6	400	48.0	12.0
1982	2,940	561	19.1	415	51.0	12.3
1983	2,940	496	16.9	415	49.4	11.9

at Chelyabinsk, Aktyubinsk, Zaporozhye, and Zestafoni were the main centers of ferrochromium production.

Despite its rank among producers, the U.S.S.R. ferrochromium exports total only about 25,000 mt annually of which about 10,000 mt is shipped to Western Europe, its major outlet in the West.

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CHAPTER 2.—CHROMIUM SOURCES

Most of the Soviet Union's total output of chromium is derived from mines in the Kazakh S.S.R. (fig. 2), most notably from the Donskoy group of deposits in the southern part of the Kempirsay massif (*1*).[1] These deposits have accounted for about 94% to 96% of chromite production in recent years. The only other currently active commercial source of primary chromium is the Saranov deposit (**2**)[2] of Perm Oblast', in the Russian S.F.S.R. In the whole of the Uralian folded region, more than 25 areas have been identified in which the mining of chromite has taken place at various times. Elsewhere, chromite has been mined in Transcaucasia in the Shorzha, Gey-Dara (**16**), and certain other ultramafic massifs (**17**) but these operations as well as numerous other deposits and ore showings, some in the Urals (**39-40**) and others in the Caucasus (**17**), Siberia (**20-31**), Kamchatka (**33-34**), Chukotka (**35-38**), and Sakhalin Island (**32**) among other places, have been unimportant, at least thus far, in terms of their contribution to Soviet chromium supplies.

The U.S.S.R.'s only other currently tapped sources of chromium are scrap and industrial wastes such as dust and slags from chemical and plating operations. Stainless steel scrap is the only sizable secondary source, but in existing Soviet practice, this source is not important; other chromium-bearing alloy scrap and industrial wastes return even lesser amounts to industry.

GEOLOGY AND MINEROLOGY

According to Smirnov (*12*, p. 178), all the chromite deposits of the U.S.S.R. occur in ultramafic massifs, distributed in the folded regions. He further notes that the largest deposits in Kazahkstan and in the Urals are of Caledonian age, and were deposited by differential crystallization of ultrabasic magmatic intrusions, primarily peridotites and dunites.

Of the small number of chromium-bearing minerals, only the chromium spinels are important commercially and serve as the unique source of metallic chromium and the products of its chemical compounds. Mineralogically, chromium spinels cannot contain more than 62% Cr_2O_3, the remainder are impurities of Al_2O_3, Fe_2O_3, MgO, MnO, and sometimes TiO_2, ZnO, NiO, CoO, and others. The content of chromium oxides as well as the Cr_2O_3-FeO ratio vary, depending upon the quantities of these impurities that are present. In the group of chromium spinels with general formula (Mg, Fe)·(Cr, Al, $^{3+}$e)$_2O_4$, the greatest interest centers around the following minerals: magnochromite (Mg, Fe)·Cr_2O_4; alumochromite (Mg, Fe)·Cr, Al)$_2O_4$; subferrichromite (Mg, Fe)·(Cr, Fe)$_2O_4$; and, to a less degree, subferrialumochromite (Mg, Fe)·(Cr, Fe, Al)$_2O_4$. These minerals have a Cr_2O_3-FeO ratio higher than 2.5:1, owing to the substitution of a part of the ferrous iron by impurities. Despite the diversity of chemical composition, the mineralogical composition of all ores is almost consistent. The Ural Mountains region and northwestern Kazakhstan, between the 50th and 60th parallels, contain nearly all the important chromite deposits in the U.S.S.R. Reported occurrences in the Caucasus, in the Pechora River basin (**39-40**), and east of Lake Baykal are evidently little more than prospects. In the central Urals, the Saranov deposit with chemical and refractory grade ore, is important, although proportionally far less significant than the deposits of Kazakhstan.

DESCRIPTION OF INDIVIDUAL DEPOSITS

Deposits of the Kempirsay Massif

The Kempirsay chromite massif lies in Aktyubinsk Oblast' of the Kazakh S.S.R., on the southern extremity of the Urals. Reportedly, chromite was first discovered here in 1920 but according to other indications the actual outcrops of chromite were not discovered until 1936, and the first of the Donskoy group of deposits (Gigant, Sputnik, Almaz-Zhemchuzhina, etc.) were discovered in 1937.

The Kempirsay massif extends almost north-south for 82 km, in conformity with the direction of the fault zone; its

[1]Italic numbers in parenthese refer to items in the list of references at the end of this chapter.
[2]Boldface numerals in parentheses refer to locations on figure 2.

MICROFICHE GRID GAUGE
NBS/NMA 1978

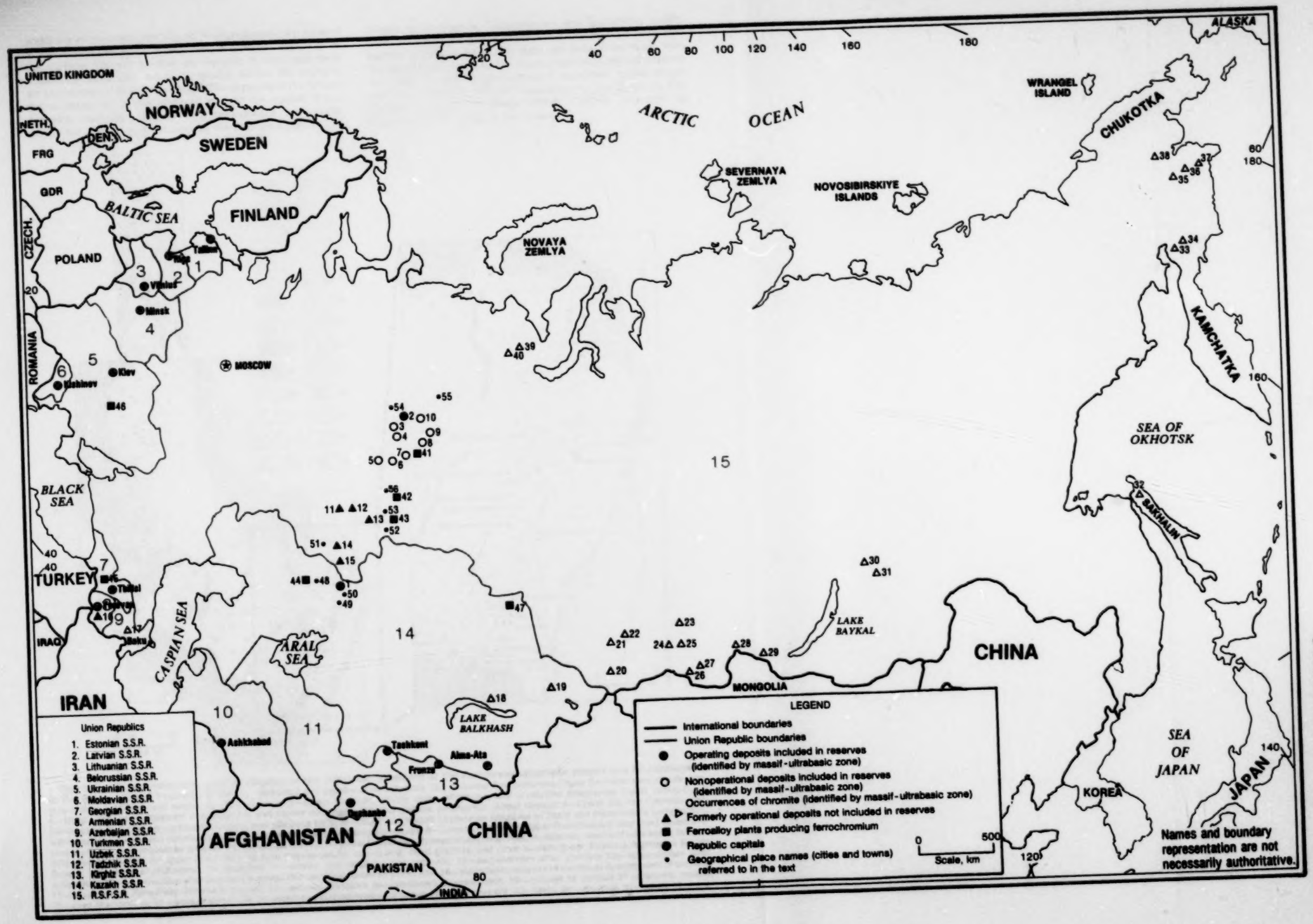

Figure 2.—Location map of Soviet chromium industry. Chromite occurrences and ferroalloy plants: 1—Kempirsay (17 deposits, for details see fig. 3), 2—Saranov, 3—Verkhne Tagil', 4—Verkhne-Nadvin, 5—Gologor, 6—Kiyuchar-Pervomay (Monastyrnaya dacha), 7—Rezhev, 8—Alapayev, 9—Nizhne-Saldin, 10—Goloustenogorsk, 11—Bol'shoy Bashart, 12—Kraka, 13—Verbiyuzhegor, 14—Khalilovo, 15—Khabarny, 16—Shorsa, 17—Azarbaydzhan, 18—Chu-Balkhash, 19—Charsk, 20—Khapesk, 21—Saisir, 22—Kuznetsk-Alatau, 23—Krasnoyarsk, 24—Shadat, 25—Ergak, 26—Agardag, 27—Uler, 28—Khara-Nur, 29—Bohir-Kiloy, 30—Perem, 31—Shaman, 32—Yushno-Tominsk, 33—Mamatchninsk, 34—Kaluyak, 35—Tamvatney, 36—Krasnogor, 37—Chirinay, 38—Ust'-Belsk, 39—Rai-Iz, 40—Voikaro-Synynsk, 41—Serov, 42—Klychev, 43—Chelyabinsk, 44—Aktyubinsk, 45—Zestafoni, 46—Zapadzhyya, 47—Yermak, 48—Aktyubinsk, 49—Orsk, 50—Khrom-Tau, 51—Orenburg, 52—Magnitogorsk, 53—Chelyabinsk, 54—Perm, 55—Kamsk, 56—Sverdlovsk.

width varies considerably. Chromite segregations are located in various sectors of the massif and at different depths from the surface. The ore bodies are variable in size, and their component ores vary widely in quality. About 160 deposits are concentrated within the massif. The deposits of the Batamshinsk zones are in the northern part of the massif. These deposits, associated mainly with periodotites, are usable mainly for refractory purposes. In the southern part of the massif, in the Stepnin, Southwestern, and Tagashasay uplifts, there are small deposits and ore occurrences. Near the southeastern arched uplift is the main ore field. Here more than 70 chromite ore deposits are distributed irregularly as clusters in a large massif of serpentinized ultrabasic rocks whose outcrops amount to 920 km^2 exposed area (see figure 3). The Southern (Donskoy) group, which consists primarily of serpentinized dunites, is the richest.

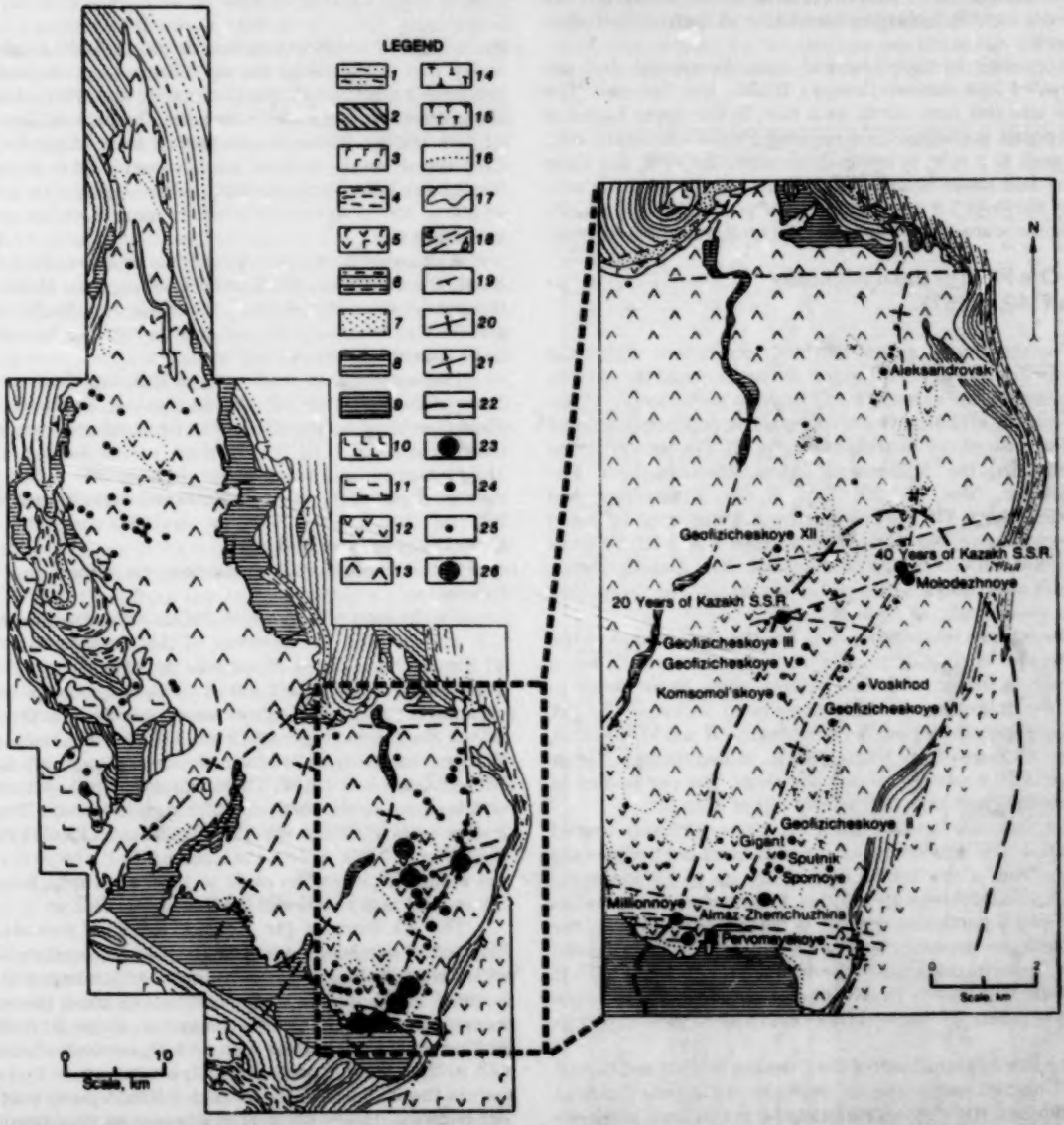

Figure 3.—Structural-petrographical diagram of the Paleozoic basement of the Kempirsay ultramafic massif and its relationship to the Paleozoic and Proterozoic rocks. (Modified and adapted from reference 12.) 1—Lower Carboniferous-Upper Devonian sandstones, conglomerates, argillites, and siltstones (Zilair Group); 2—Upper Devonian cherty rocks, siltstones, and crystalline limestones (Egida Group-D_{3-C_1}); 3—Middle Devonian (Givetian) coarse-pebbly and blocky conglomerates and diabase porphyrites (Altpel Group); 4—Lower Silurian (Llandoverian-Wenlockian) diabases, amygdaloidal basalts, and siliceous tuffs; 5—Lower and Middle Ordovician eruptives of basic and intermediate composition, tuff-sandstones, siliceous schists, conglomerates, and limestones (Kuragash Group); 6—Lower Ordovician (Upper Tremadocian) clay-chert slates with seams of quartzites, arkosic sandstones, and siliceous tuffites; 7—Lower Ordovician (Tremadocian) aregillites, sandstones, seams of tuffs and siltstones (Kidrasyovsk Group); 8—Upper Proterozoic sericite-chlorite-quartz, clay-quartz, chert-graphite, and other schists (lower Kayala subgroup of Kayala Group); 9—gabbro-amphibolites; 10—gabbros; 11—olivine and amphibolized gabbros; 12—serpentinites after dunites; 13—serpentinites after peridotites; 14—serpentinites after pyroxene dunites; 15—undifferentiated serpentinites; 16—boundaries of areas of maximum development of dunites; 17—boundary of Kempirsay ultramafic massif; 18—tectonic fractures (a—confirmed, b—assumed); 19—altitude of contact of ultramafic massif; 20—axes of anticlines; 21—axes of synclines; 22—outline of magma-feeding channel; Chromite deposits: 23—large, 24—medium, 25—small; 26—lean disseminated ores.

The ores of the Kempirsay massif vary considerably in composition. The content of oxides varies within the following limits in percentage: Cr_2O_3, 20 to 63; FeO (total), 7 to 21; MgO, 8 to 20; Al_2O_3, 8 to 15; SiO_2, 0.2 to 30; P, trace to 0.03; and Ni, trace to 0.35. The chief ore-forming mineral, magnochromite, has the following empirical formula: Cr_2O_3—63.8%, FeO (total)—13.5%, Al_2O_3—8.9%, and MgO—17.4%.

The Kempirsay ores include both lumpy ores, in which the amount of ore grains exceeds 80% of the volume, and disseminated ores, in which the magnochromite grains are cemented, usually by serpentine with small impurities of other minerals.

According to their physical state, Kempirsay ores are subdivided into massive (lumpy), friable, and fine ores. The friable and fine ores occur, as a rule, in the upper layers of the deposits, sometimes outcropping. Friable chromium ores are found, as a rule, in lower layers than fine ores, and lump ores in still lower layers. The specific gravity of these ores ranges between 3.8 and 4.3, and their porosity is 19% to 34%. The fine ores are about 4% to 6% of the total chromite reserves.

Main Ore Field of the Kempirsay Massif (*12*, p. 187)

The chromite deposits and ore occurrences within the main ore field occur in two zones, the western and the eastern. The western zone extends for 22 km in a northeasterly direction. Near the Millionnoye-Pervomayskoye deposits, it merges with the eastern ore-bearing zone (fig. 3). The western zone has included the Millionnoye, Almaz-Zhemchuzhina, Pervomayskoye, Nos. 16, 29, 29A, 31, 39, Khrom-Tau, and Geofizicheskoye VII. Farther northward, this zone included Komsomol'skoye, No. 4, Geofizicheskoye V and III, 20 Years of the Kazakh S.S.R., Geofizicheskoye XII, Aleksandrovsk, Iyun' deposits, and a series of ore showings. The ore bodies have a westerly dip of from 15° to 75°.

The eastern ore-bearing zone has the same extent as the western and is roughly parallel to it. In the north, it has a tendency to merge with the western zone. From south to north the following deposits have been included: No. 21, Spornoye, Sputnik, Gigant, Geofizicheskoye II and VI, Voskhod, Solovey, 40 Years of the Kazakh S.S.R., Molodezhnoye, Vkraplennoye, and a number of ore showings. The ore bodies of the deposits here have an easterly dip of 0° to 50°.

The deposits form an extended series of closely spaced ore bodies. The dimensions of the individual ore bodies vary widely—from a few tenths of a meter up to 1.5 km along strike, with a thickness up to 150 m. The number of ore bodies comprising a particular deposit is varied. For example, the Molodzehnoye deposit consists of only one large body, the Almaz- Zhemchuzhina has 5, the 40 Years of the Kazakh S.S.R. 15, and the Millionnoye 99. The bodies are separated by segregations of dunite, pyroxene dunites, and less frequently, peridotites.

The raw material base of the Donskoy Mining and Beneficiation Complex comprises the deposits of the main ore field. This complex, the only operational unit in this area, produces about 94% to 96% of the total Soviet chromite. The variable nature of the different crude ores from these deposits is shown in table 6.

In terms of deposit size and ore quality, the deposits fall into two types. The small and low-grade deposits consist of pockets and lenses with thicknesses of 20 to 30 m. These deposits have particularly complex structures; the mineralization is irregular with many isolated sections in the ore bodies; consequently during extraction the quality of the ore is lowered appreciably by dilution. Deposits of the second type have

Table 6.—Chemical composition of Donskoy ores from selected deposits, percent (*12*, p. 192)

Deposit	Cr_2O_3	FeO	SiO_2	CaO	P
Almaz-Zhemchuzhina . .	49.05	12.5	8.1	0.42	0.002
Geofizicheskoye VI . . .	55.0	12.2	4.9	0	.020
Geofizicheskoye XII . . .	10.5	8.4	29.2	.23	.001
Komsomol'skoye	49.6	11.6	7.0	0	.012
Millionnoye	49.5	12.3	5.2	0	.008
Pervomayskoye	46.0	14.8	9.4	.3	.001

ore bodies of considerable length (up to 3,000 m along the strike and 650 m along the dip). These large deposits have ore bodies with complicated branching and sharp changes in thickness along both strike and dip. The ores are lumpy and of high quality. The northern part of these deposits, where they appear on the surface, has been depleted or is currently being mined. The southern flanks of the deposits are at depths of 300 to 400 m and preparations to mine them are currently underway (*5*).

Along with the large deposits (the 20 Years of the Kazakh S.S.R., the 40 Years of the Kazakh S.S.R., and the Millionnoye), the smaller deposits, Melkoye, Spornoye, Nos. 16, 38, and 29A, and Geofizicheskoye V, are currently being mined or are about to be mined by open pit method (*10*).

The outcropping ore bodies of the main field are the 20 Years of the Kazakh S.S.R., Gigant, Sputnik, Spornoye, Almaz-Zhemchuzhina, among others. The depth of occurrence of the Geofizicheskoye I, III, VI, 40 Years of the Kazakh S.S.R.—Molodezhnoye, and some others is from 300 to 500 m. The average depth of the other deposits are Almaz-Zhemchuzhina, 863 m; Millionnoye, 563 m; and Pervomayskoye and Molodezhnoye, over 500 m.

Detailed information on the deposits of the main ore field follows.

The 20 Years of the Kazakh S.S.R.—According to Smirnov (*12*, pp. 195-197), ore reserves of this deposit, 9 km north of Khrom-Tau, exceed 25 million mt with a Cr_2O_3 content above 50% in categories $A + B + C_1 + C_2$. There are 60 separate chromite bodies, of which 10 are economic. The ore bodies have a maximum length of 1.9 km, with a width ranging from 40 m in the north to 240 m in the central part; dip is 10° to 50° and pitch is 5° to 10°. The maximum depth of mineralization is 40 m in the north and 320 m in the south. These ore bodies contain 22% to 62% Cr_2O_3, 1.3% to 21.7% SiO_2, 9.2% to 15.1% Fe_2O_3, 0.22% to 1.3% CaO, and 0.03% P. The 10 economic ore bodies have lengths of 80 to 1,350 m, widths from 33 to 130 m, and cross-sectional thicknesses from 3 to 55 m.

The 40 Years of the Kazakh S.S.R.–Molodezhnoye.—These two deposits have been considered together because exploratory drilling has shown that they are linked at depth. Located in the middle of the eastern ore zone, the reserves in categories $A + B + C_1 + C_2$ amount to about 90 million mt in 23 separate ore bodies, with a Cr_2O_3 content of about 50% (*12*, p. 197). Both deposits contain lumpy ore.

In the 40 Years of the Kazakh S.S.R. deposit, part of the ore bodies is almost horizontal, whereas another portion generally dips westwards at 10° to 25°. In the northern end of deposit, mineralization appears on the surface, and in the south it occurs at depths of 300 to 350 m. The largest ore body, No. 4, extends for 934 m, with a width of 200 m and a maximum thickness of 65 m. The ore body next in size, No. 3, has a length of 664 m, a width of 282 m, and a thickness of up to 85 m. Other bodies along strike are from 50 to 420 m long, with widths of 50 to 100 m, and thicknesses of 5 to 40 m.

The Molodezhnoye deposit, the largest in the ore field, extends for 1,540 m, with a width of from 200 to 300 m, and

a maximum thickness of 140 m. The body occurs at depths of 422 to 600 m. The ores of the deposit contain 19.3% to 58.95% Cr_2O_3, 0.3% to 30.0% SiO_2, 9% to 14.5% Fe_2O_3, trace to 0.84% CaO, and up to 0.005% P.

Millionnoye.—This deposit consists of two ore bodies each with a highly variable thickness ranging from 3 to 131 m. The No. 1 ore body has a length along strike of 1,500 m and the No. 2 ore body extends 700 m along the strike. Dip of the ore bodies is 25° to 36° with an average depth of 562.7 m, and a maximum depth of 1,100 m (*6*, p. 24). Reserves of ores, with an average Cr_2O_3 content of 49.5% (*12*, p. 192) are described as large, without further specifics.

Almaz–Zhemchuzhina.—Exploratory drilling has established that the four ore bodies of this deposit have a length of 500 to 1,900 m and a thickness of 3 to 80 m. The depth of occurrence varies from 159 to 1,500 m (*6*, p. 24), and ore reserves with an average Cr_2O_3 content of 49.05 (*12*, p. 192) are described as large.

The following main ore field deposits are of medium size: Pervomayskoye (four ore bodies with an average thickness of 38 m, an average length of 340 m, and up to 442 m in depth), deposit No. 21 (four ore bodies), Geofizicheskoye VI, Geofizicheskoye XII, and Spornoye (*5*).

The main ore field also has at least a dozen deposits with small reserves including Voskhod, Komsomol'skoye, Geofizicheskoye II, Geofizicheskoye III, Geofizicheskoye I, Ob'edinennyy, Sputnik, Yuzhnyy, Aleksandovskoye, and others (*5*).

Other Kempirsay Deposits

In the northern portion of the Kempirsay massif over 30 small deposits and ore shows have been counted in the Batamin ore field. Ores from this region display a relatively low content of Cr_2O_3 (32% to 38%) with a Cr_2O_3-FeO ratio varying from 2.1:1 to 2.8:1.

Fifteen kilometers north of Kempirsay village, the Baranov chromite deposit is sited near the Baranov nickel deposit. The Baranov chromite deposit can be traced on the surface for 135 m with a thickness of from 5 to 10 m. The average Cr_2O_3 content of the ores of this deposit is 37.08% and the Cr_2O_3-FeO ratio is 2.6:1. The ores of this and other deposits of the Batamin ore field are suitable mainly for refractory and chemical industries (*12*, pp. 199-200).

DEPOSITS OF THE URALS

There are some 300 occurrences of chromite in the Urals within the Russian S.F.S.R., 30 of which have been mined. The chromite is found at shallow depths, usually 10 m, rarely as deep as 30 to 40 m, in veins in the areas of serpentine and peridotites. Most small deposits and ore showings are still untouched or are explored only to a very small degree.

The deposits lie in a belt of ultrabasic rocks extending from Khalilovo (**14**), near Orenburg (**51**) in the south, northward to Sverdlovsk (**56**), then continuing 112 km north-northwest to Nizhniy Tagil and on to Saranov. Chromite from the Urals, which has a low Cr_2O_3 content (20% to 40%) as well as a low Cr_2O_3-FeO ratio, is mostly used in the chemical and refractory industries. The most important is the Saranov deposit in Perm Oblast'.

Detailed information on selected deposits of the Urals follows.

Saranov Deposit (12, pp. 215-223).—The main Saranov chromite deposit lies on the western slope of the Urals in the Chusovo district of the Perm Oblast'; about 250 km from Sverdlovsk.

According to Soviet estimates, the Saranov chromite-bearing gabbro-peridotite massif, of very small dimensions, possesses about 14 million mt of chromite ores. Outcrops of the ultramafic rocks cover 0.22 km^2 with a length of 1,700 to 1,800 m and average width of about 200 m. The maximum width of the massif itself is about 400 m. The contacts of the ultramafic massif are conformable with the country rock (figs. 4-5).

Commercial ore concentrations occur in three parallel ore bodies. The central body extends for 1,200 m, with a thickness of 10 m; the western extends 910 m and is 5 m thick; and the eastern extends 1,100 m and is 3 to 3.5 m thick. The

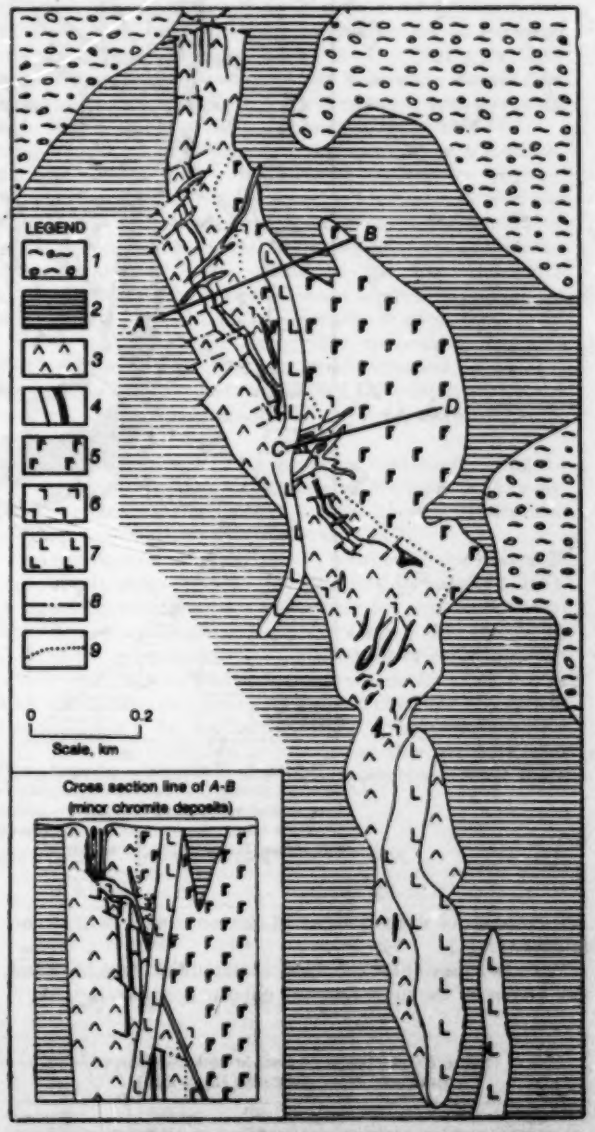

Figure 4.—Diagramatic geological map of the northern Saranov chromite-bearing massif. (Modified and adapted from reference 12.) 1—Alluvial cobbly-clay sediments; 2—quartz-sericite, quartz-sericite-chlorite, epidote- and actinolite-chlorite schists, etc.; 3—apo-periodititic serpentinites; 4—chromite ore bodies; 5—gabbro-norites; 6—metamorphosed diabases; 7—gabbro-diabases; 8—tectonic disturbances; 9—boundary between periodites and gabbro-norites.

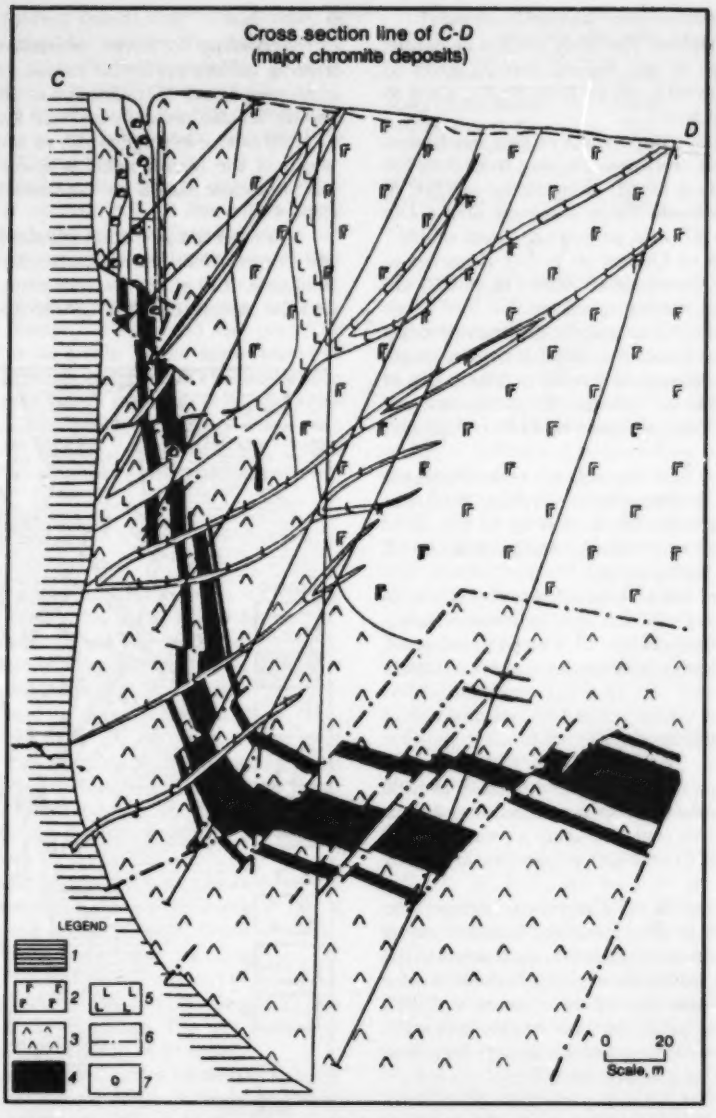

Figure 5.—Enlarged east-west geological section through the main Saranov deposit along C-D section. (Modified and adapted from reference 12.) 1—Schists; 2—gabbros and gabbro-norites; 3—peridotites; 4—densely segregated and massive chromite ores; 5—vein rocks: gabbro-diabases, porphyrites, etc.; 6—tectonic disturbances; 7—underground workings.

ore consists of about 95% of chromium-spinel, with some silicates (fig. 3).

The average chemical composition of the three principal ore bodies of the main Saranov deposit is shown in table 7.

Table 7.—Average chemical composition of Saranov ores, percent (*12*, p. 221)

Component	Western	Central	Eastern
Cr_2O_3	34.13	38.24-39.12	34.40
Al_2O_3	18.94	17.50-18.80	18.83
$FeO + Fe_2O_3$	17.91	18.53-20.27	21.26
MgO	14.73	14.67-15.16	13.48
SiO_2	5.56	4.00- 5.00	6.10
CaO	4.64	1.36- 1.46	.92

The ores have been used as refractory and chemical raw materials.

Klyuchev Deposit (12, pp. 205-209).—The Klyuchev (**6**) chromite field occurs in an ultramafic massif of the same name, located on the eastern slopes of the central Urals 50 km from Sverdlovsk. The massif, about 80 km^2 in area, is mushroomlike in plan. It extends 17 km north-south, reaching 8 km in width in the south, and decreasing to 1 to 3 km in the north.

About 200 small deposits and ore occurrences are known in the Klyuchev massif. The largest of them are the Revdin, Pervomay, Kozlov, and Samokhvalov group of deposits. The ore bodies of the Klyuchev massif reportedly vary in thickness from 5 to 20 m, range in length up to 350 m, and average 13% to 18% Cr_2O_3, but there is a wide variation in grade from ore

body to ore body. It has been indicated that there is a predominance of ore containing only 8% to 10% Cr_2O_3 but in places, higher grade ore may be found in areas of limited extent. Detailed reporting on these deposits lists disseminated ores in three categories (under 15%, 15% to 30%, and 30% to 40% Cr_2O_3) as well as some lumpy ore (40% to 45% Cr_2O_3).

Verblynzhegor Deposit (12, pp. 241-245).—Mining came to an end here with the expansion of the Donskoy group of mines. The Verblynzhegor massif (**13**) has an area of about 50 km^2, is 16 km long with a width in the southern part of 5.5 km. At the present time, the deposits have no economic importance.

There are many other small deposits of chromite in the Ural Mountains (Khalilov, Alapaev, Gologor, Monetnaya Dacha, etc.) but most seem of little economic importance.

OTHER DEPOSITS OF THE U.S.S.R.

The Shorzha massif, located in the Krasnosel'sk district of the Armenian S.S.R. on the northeastern coast of Lake Sevan near Shorzha, is the chief area of chromite deposits outside Kazakhstan and the Urals. The massif includes more than 10 small deposits and ore showings. The dimensions of ore bodies are small, up to 25 to 30 m in length, with a thickness of 1 to 4 m and a width of 3 to 10 m. They extend for 30 to 35 m downslope (*12*, pp. 201-204). The chemical composition is varied. Thus, for example, in the ores of Shorzha deposit No. 2, the Cr_2O_3 content is 32% to 35% with about 25% Al_2O_3, and total iron, calculated as FeO, is about 16%. The ores of the other deposits, for example, deposits No. 27 and No. 28, are considerably richer in chromium and are less aluminous, with more than 45% Cr_2O_3, 10% to 14% Al_2O_3, and about 16% to 20% FeO.

There are also small deposits of chromite in the North Caucasus, Siberia, and other regions of the U.S.S.R. (fig. 2). At least to the present, little economic significance has been assigned to other chromite deposits in the U.S.S.R. Reserves of some 10 million mt in categories A, B, and C_1, and 30 million mt in category C_2 in the massif of the Tuvin region of Siberia (**26**) near the Mongolian border are evidently regarded as not exploitable. Similarly, deposits or occurrences in the north Caucasus, Siberia, Kamchatka, Chukotka, Sakhalin, and the extreme northern Urals are evidently regarded as not commercially exploitable because they are too small, too low in grade, too inaccessible, or unsatisfactory for some combination of these factors.

CHROMITE RESERVES

The present size of the Soviet reserves of chromite is one of the least known aspects of the mineral economy of the country. In order to provide a historical basis for examining more recent Soviet reserve data, as well as to provide a comparison between historic reserve data and historic production, table 8 is presented.

In the central Urals, the Saranov deposit, with some 13 million mt of chemical and refractory grade ores, was the principal Soviet chromite producing area until after 1937, when the Kempirsay deposits were discovered. During World War II, the Kempirsay deposits were brought into production. The total estimated reserves of chromite in 1941, according to Soviet sources, exceeded 27 million mt in categories $A+B+C_1+C_2$, including over 14 million mt of explored exploitable reserves (categories $A+B+C_1$). During the 1945-58 period, exploration work in the Kempirsay massif continued and total explored exploitable reserves were increased from 14 million mt in 1945 to 98 million mt in 1958 (*10*).

Soviet publications indicate that chromite was a perennial high-priority item in the national exploration program. In 1960, the 40 Years of the Kazakh S.S.R. and in 1966 the Molodezhnoye deposits were discovered in the Kempirsay region. A considerable part of these deposits was suitable for opencast mining. The reserves in the categories $A+B+C_1+C_2$ of these two deposits totalled 90 million mt of chromium ores with a Cr_2O_3 content of about 50%.

By 1965, explored exploitable reserves (categories $A+B+C_1$) in the U.S.S.R. had been increased by 40% (*9*) compared with those of 1958, totaling 137 million mt, but the reserves of rich chromite ores in the Kempirsay field were limited (*4*).

The exploration for chromium ore continued during the 1965-70 period. Detailed exploration of Millionnoye, Alamaz-Zhemchuzhina, Pervomayskoye, and No. 21 chromite deposits in Kempirsay region was completed in 1970.

According to an official Soviet source (*1*), there were 28 explored chromite deposits in the U.S.S.R. on January 1, 1971. Of these, 26 were regarded as suitable for exploitation, and these deposits collectively had reserves in Soviet categories A, B, and C_1 aggregating 271.2 million mt of ore containing 32% or more Cr_2O_3. The same source indicated that Soviet reserves represented 18% of total world chromite reserves at that time, but it did not indicate what source was used for data for other countries in calculating this percentage. It appears evident, however, that in computing the U.S.S.R. share

Table 8.—Growth of reported Soviet chromite reserves in place,[1] 1928-38, thousand metric tons

Reserve estimate date	A	B	C_1	$A+B+C_1$	C_2	$A+B+C_1+C_2$
1/1/28	NA	NA	NA	NA	NA	6,000
1/1/33	1,816	2,857	3,630	8,303	6,443	14,746
1/1/34	2,059	2,838	3,854	8,751	6,443	15,194
1/1/36:						
>40% Cr_2O_3	255.0	137.6	113.1	505.7	3,032.0	3,537.7
<40% Cr_2O_3	1,730.0	2,923.2	3,602.3	8,255.5	7,467.7	15,722.2
Total	1,985.0	3,060.8	3,715.4	8,761.2	7,498.7	19,259.9
1/1/38:						
>40% Cr_2O_3:						
Urals of R.S.F.S.R.	195		63	258	NA	NA
Kazakhstan	1,070		626	1,696	NA	NA
Total	1,265		689	1,954	NA	NA
<40% Cr_2O_3: Urals of R.S.F.S.R.	3,694		2,938	6,632	NA	NA
Total	4,959		3,627	8,586	NA	NA

NA Not available. [1]See figure 1 for category definitions.

Sources: 1928 (*3*), 1933 (*2*, p. 109), 1934 (*14*), 1936 (*8*), 1938 (*2*, p. 111).

Table 9.—Soviet explored exploitable reserves of chromite in place, reserve categories A, B, and C_1, January 1, 1971

Region	Deposits	Reserves,[1] 10^3 mt			Regional share of national total, %
		A+B	C_1	Total	
Kazakhstan, Aktybuinsk Oblast', Khrom-Tau vicinity	17	108,585	142,847	257,432	94.9
Urals, Perm Oblast', Saranov, and others	9	2,765	11,029	13,794	5.1
Total	26	111,350	153,876	271,226	100

[1] ≥32% Cr_2O_3; Cr_2O_3 ratio ≥2.5:1; see figure 1 for category definitions.

of this world total, the Soviets evidently included for the U.S.S.R. a fairly substantial but unreported quantity of material in the C_2 category in addition to all material classified as A, B, and C_1, and quite possibly some additional A, B, C_1, and/or C_2 category material that was evaluated as either too inaccessible or of too low a grade for exploitation, or both.

In considering that material classified as exploitable, it should be noted that another Soviet source (*13*) of the same vintage as that from which the 1971 reserve quantities were taken, indicated that material included as exploitable had a Cr_2O_3-FeO ratio of 2.5:1. These ores were confined to the two main chromite mining areas as shown in table 9.

Of the ore deposits credited to Aktyubinsk Oblast', the 40 Years of the Kazakh S.S.R.–Molodezhnoye deposits and the Almaz-Zhemchuzhina deposits together account for 85 million mt of the regional total of 257 million mt. The deposits of the Urals, most notably the operating Saranov deposit, are regarded as having lower chromite contents and Cr_2O_3-FeO ratios than those of Aktyubinsk Oblast' and are regarded primarily as suitable for use in the chemical and refractory industries.

During the 1970's, continued exploratory work in the Donskoy field of Aktyubinsk Oblast', especially in the deep parts of the Almaz-Zhemchuzhina and Millionnoye deposits, resulted in the addition of at least 7.55 million mt to Soviet reserves, this quantity being reported as explored, exploitable reserves (*11*). On the other hand, mining activities during the 13-yr period 1971-83 resulted in the depletion of the Geofizicheskoye II, III, and VI and Sputnik and No. 4 deposits, as well as part of the 20 Years of the Kazakh S.S.R. and Almaz-Zhemchuzhina deposits, reducing the 1971 reported reserve total by about 50 million mt of materials with an average Cr_2O_3 content of about 52% (*6*, p. 8). On the basis of the 1971 reported exploitable reserve and the foregoing additions to and withdrawals from reserves, the total in-place explored, exploitable chromite reserves of the Soviet Union on January 1, 1984, can be calculated at about 229 million mt, assuming that all significant additions to the explored, exploitable reserve have been reported in the Soviet press.

It is important to bear in mind when examining the question of the magnitude of Soviet reserves that the Soviets have used the foregoing reserve figures in planning their mine and concentrator development programs during the 1970's and early 1980's. Thus these reserve figures reflect the basis for their investments in mine and beneficiation plants as well as for actual development work described subsequently in this report. Just as it would be illogical to apply Soviet standards for evaluating the potential of a mineral deposit to any deposit outside the U.S.S.R. and its CMEA associates, so too would it be illogical to apply western standards of evaluating the commercial potential of a deposit to Soviet or other CMEA deposits. Simply put, these figures represent, as best can be determined, the Soviet chromite reserves, because these are the figures that the Soviets use for planning.

In conclusion, three points should be stressed: (1) The 229 million mt reserve figure does not include reserves in the C_2 category, (2) the reserve figure does not include material in any classification category that is outside the scope of the "balansovye" or exploitable range (see chapter 1), (3) although the reserve figure contains very substantial reserves in the Khrom-Tau region of Aktyubinsk Oblast', mining activities there during 1971-83 have significantly reduced supplies of the richer ore amenable to surface mining, and this has been noted in the Soviet literature. For example, Kazakhstanskaya Pravda (*7*) reports: "The reserves of chromite at the Donskoy complex are already not large." There is need for development of underground mines as well as for facilities for concentration of lower grade ores. Regarding the underground mining, which has already started, the raw material base of the Donskoy complex can be relied upon for future development of chromite extraction by underground mining. In connection with the latter, it has been noted that the hydrogeological conditions of the deposits are favorable, there being only an insignificant influx of subsurface water, 40 to 160 m^3 per hour (*12*, p. 192).

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CHAPTER 3.—TECHNOLOGY AND PRODUCTION

PROSPECTING AND EXPLORATION

There are more than 20,000 explored mineral deposits in the U.S.S.R., including 28 recorded as chromite deposits. Of the total, over 5,000 deposits were being exploited in 1983, including 6 chromite deposits. Up to 40% of capital investment in industry is spent on exploration and mining of minerals but there are no specific published details for chromium. Expenditure on total geological prospecting during the years from 1950 to 1980 increased by a factor of eight, and in 1980 it amounted to about 5 billion rubles. This amount is projected to increase annually by 5% to 8%. Extensive prospecting and exploration for practically all commodities is carried out on a large scale. There were over 500,000 employees in the geological and prospecting organizations in 1980, including over 120,000 graduate specialists with university or technical education. The U.S.S.R. Ministry of Geology and Conservation of Mineral Resources had 36 research institutes and 2 design establishments with a total staff of over 40,000 in 1982. Every year the Ministry of Geology and Conservation of Mineral Resources alone completes more than 20 million m of core well drilling, over 3 million m of petroleum and gas wells, and about 300,000 m of various underground mining excavations. The geologists have at their disposal more than 10,000 drilling rigs.

The State Commission on Mineral Reserves, under the U.S.S.R. Council of Ministers, has the following functions in relation to prospecting and exploration:

Checking reserves calculations regardless of which ministry carried out prospecting work.

Determining the degree and reliability of the study as well as whether the deposit is ready for industrial operation, in accordance with the established classification of reserves and with the necessary proportion of reserves of different categories.

Deciding whether useful associated minerals of an ore deposit might be recovered.

Providing methodical guidance and control to territorial commissions on mineral reserves.

Soviet publications indicate that chromite is a perennial high-priority item in the exploration program. A number of rich chromite deposits, which were suitable for opencast mining, were depleted during the last decade. As result of this depletion, capital investments on chromite exploration were increased by 32% during the 1971-75 period as compared with investments of 1966-70 (*27*).[1] Detailed exploration of the deepest parts of the Almaz-Zhemchuzhina, Millionnoye, and other deposits was completed during the 1970's. Table 10 provides data on the density of the reconnaissance grid actually used for the foregoing and for other notable chromite deposits in the U.S.S.R.

The deposits that have been depleted were rather fully explored, and there has been a high level of agreement between reserves indicated by exploration and the results of exploitation. For the Geofizicheskoye II, Sputnik, No. 4, Geofizicheskoye III, and Geofizicheskoye VI deposits (fig. 3), as well as the northern parts of the 20 Years of the Kazakh S.S.R. and the Almaz-Zhemchuzhina deposits, the total calculated explored, exploitable reserves in place were 48.8 million mt of ore with an average chromium oxide content of 51.9%. The recoverable reserves for these deposits were 45.8 million mt of ore with a Cr_2O_3 content of 52.5%. The actual extraction figure was 46.3 million mt of ore with an average chromium oxide content of 53.3% (*9*, p. 8).

Currently, deposits are being developed with exploratory boreholes spaced at 50- to 100-m intervals along the strike and 40 to 80 m along the dip. When the quantity of reserves and quality of the ore estimated on the basis of exploration are compared to actual figures from exploitation, a ratio of 1.2 m of exploratory drilling to thousand metric tons of ore is found to be adequate for planning. To provide full information on the geological structure and the qualitative characteristics of the ore, a large amount of exploratory drilling (with a spacing of 20 to 30 m) is conducted on the chromium deposits, as shown in table 10.

Despite evidence of relative success in exploration of chromite deposits, Soviet personnel have expressed dissatisfaction regarding actual performance of exploration work parties, noting specific problems, including the following (*28*):

A significant number of boreholes drilled were sited outside the limits of commercial mineralization, and therefore they did not contribute significant information on the ore body.

Results of drilling were undervalued in estimating reserves.

Cores recovered were of poor quality owing to poor drilling techniques.

Exploration teams did not provide sufficient geophysical research.

General documentation on and descriptions of core samples and other workings were of poor quality.

"In another instance (*25*), it was noted that geologists were receiving neither the correct type nor sufficient quantities of exploratory drilling equipment from the responsible

[1]Italic numbers in parentheses refer to items in the list of references at the end of this chapter.

Table 10.—Spacing of reconnaissance grid[1] in exploration and exploitation of chromite deposits, meters (*20*)

Reserve categories (fig. 1)	A		B		C_1	
	Along strike	Along dip	Along strike	Along dip	Along strike	Along dip
Large deposits:						
Saranov	NAp	NAp	60-100	50-100	50-100	100-200
20 Years of the Kazakh S.S.R.	NAp	NAp	100	40- 80	NAp	NAp
40 Years of the Kazakh S.S.R.	NAp	NAp	40	40	40	80
Medium deposits:						
Almaz-Zhemchuzhina	NAp	NAp	25- 40	25- 40	NAp	NAp
Geofizicheskoye	20	20	20- 50	20- 25	40	30
Komsomol'skoye	20	20	30- 40	20	NAp	NAp
Mestorozhdeniye No. 4	20	20	40	40	NAp	NAp
Millionnoye	10-20	10-20	20	20	NAp	NAp

NAp Not applicable. [1]Distance between boreholes or mining works.

agency, the Ministry of Chemical and Petroleum Machine Building.

MINISTRY OF GEOLOGY AND CONSERVATION OF MINERAL RESOURCES

Under the complex Soviet system of industry-oriented ministries, this Ministry has primary responsibility for preliminary as well as detailed exploration for all minerals. Soviet sources provide few specifics on chromite exploration, but it should be understood that, as with other commodities, chromite exploration is conducted within this organizational framework.

Immediately after the revolution in 1917, the Geological Prospecting Trust (Soyuzgeorazvedka) was formed. This trust was later reorganized into the Geological Prospecting Department, and in 1938, the Committee on Geology was set up under the Council of Ministers. In 1946, the Ministry of Geology was established, and in 1953, the Ministry was reorganized into the Ministry of Geology and Conservation of Mineral Resources and is today the highest state geological body in the U.S.S.R.

The Ministry carries out all broad-scale geological work in the Soviet Union. In addition, other ministries, such as coal, petroleum, gas, ferrous metallurgy, nonferrous metallurgy, chemical, and building materials have their own geological departments in order to study deposits that concern them in particular.

The main functions of the Ministry are as follows:

Systematic geological study and mapping of the whole country.

Extensive searching and prospecting for new deposits, including the determination of the ore reserves of these deposits for possible development.

Detailed prospecting of known mineral-bearing areas and preparation for their exploitation.

Correlation of all geological data throughout the U.S.S.R.

In addition to these main functions, the Ministry prepares plans for the development of newly discovered deposits and mining areas for the State Planning Committee.

Because of the vastness of the country, the Ministry carries out its work through several main regional (territorial) geological departments, including some ministries of geology in the union republics. Parallel to the territorial departments but working independently are the territorial commissions on mineral resources. After a mineral-bearing area has been carefully surveyed and prospected, a regional department submits its report to the appropriate commission on reserves, which then checks the reliability of the data.

In keeping with the 5-yr plans of the Government, the Ministry works out its survey and prospecting program for each 5-yr plan period from which an annual prospecting program is decided. Lists of the country's mineral reserves are drawn up and revised every year.

The Ministry also controls the rate of exploitation of deposits, endeavors to reduce losses in mining, and sees that all components of complex ores are utilized.

In addition to the Ministry's broad-scale geological work, the geological department of the Ministry of Ferrous Metallurgy carries out the following more detailed work:

Further prospecting of iron ore, manganese, and chromite deposits being mined for the purpose of discovering additional ore reserves and/or of putting resources in higher categories.

Detailed geological mapping of known chromite deposits on a scale of 1:10,000 or larger in order to obtain a more clear view of each deposit and to help in directing mining operations.

Study of the mining geology of chromite areas.

Study of the reserves of all useful associated minerals in the ores; calculation and revision of ore reserves, which are needed in planning for production.

Hydrogeological and other geological investigations of mining areas.

MINING

An overriding concern governing development of the Soviet chromite industry is the governmental mandate that the industry provide an adequate amount of chromite for national self-sufficiency and required export at any cost. Success in planned production is assessed primarily by quantity of output; considerations of quality and economic efficiency play secondary roles. Under these circumstances, efficient mechanization of mining operations is severely restricted.

Mine managers may mechanize operations only to the extent permitted by approved plan directives and by budgetary appropriations specifically earmarked for this purpose. Managers must accept whatever machines are supplied according to the plan, regardless of their quality and fitness, simply because there is only one supply source. Soviet mine managers, unlike their Western counterparts, are not worried that competitive costs may force their enterprises out of existence, but that they must meet their planned quantitative production quotas.

In 1983, three open pits and two underground mines in the U.S.S.R. produced an estimated 3.35 million mt of crude (2.94 million mt marketable) chromite. Approximately 82% of all ore was mined by open pit method.

Open Pit

All three Soviet open pits are within the Donskoy complex and are mechanized enterprises; annual production levels of these pits varies from 0.4 to 1.0 million mt of crude ore. The mining operations follow a single general pattern: drilling, blasting, loading, ore haulage to crushing and sorting mills, and overburden haulage to dumps.

A multibench mining method is used, with a bench height of 10 to 20 m. The open pits are scheduled for operation on a three-shift per day, 7-day week work schedule, but shovels and dump trucks are reportedly idle some 50% of working time (*5*, *18*). Primary blastholes of 112-mm diameter are drilled with SBSh-200 drills. The muck is loaded by single-bucket shovels of two types: EKG-4.6 (bucket capacity, 4.6 m^3) and EKG-8 (bucket capacity, 6 and 8 m^3).

Soviet designed dump trucks are used for transportation at most open pits, chiefly the Bel AZ-540 (27 mt) and Bel AZ-548 (40 mt). Trucks with a capacity of 75 mt are being tested on a commercial scale. Additionally, in the 40 Years of the Kazakh S.S.R. open pit, 109-mt-capacity Unit Rig M-120 trucks imported from the United States are in use. The operating characteristics of these units are shown in table 11.

Table 11.—Operating characteristics of U.S. manufactured M-120 trucks used for mining operations in the U.S.S.R. (*11*, pp. 14-15)

	1977	1978	1979	1980
Load capacity[1] ..... 10^6 mt/yr ...	1.4	1.6	1.6	1.5
Av transportation distance ..... km ...	1.77	1.8	1.9	2.01
Use of working time ..... % ...	73	69	64	61
8-h shift load ..... mt ...	1,591	2,005	2,168	1,129

[1]1 truck.

According to reference 37, surface mining accounted for 70% of the Soviet chromite production in 1955, but increased to 94% in 1975, before large-scale underground expansion.

Underground

Eighteen percent of all Soviet chromite ore mined was obtained from underground workings at the Donskoy complex (Khrom-Tau) and the Saranov Mine (Central Urals) in 1983. Small underground operations at the Saranov Mine started in 1938. The first stage of the Molodezhnaya underground mine at Donskoy was reported to have produced its first output in March 1982 and was projected to reach its design capacity of 800,000 mt with a Cr_2O_3 content of 45% to 51% by 1985; total annual capacity of this mine ultimately is to reach 2 million mt of crude ore. The mine will be worked through three 6.1-m-diam, 720-m-deep shafts.

In addition to the Molodezhnaya Mine, the Tsentral'naya underground mine is under development for the mining of deep parts of the Millionnoye, Almaz-Zhemchuzhina, Pervomayskoye, and No. 21 deposits. The planned maximum depth of the four shafts is 1,200 m. The capacity of Tsentral'naya is to be 3 to 4 million mt of crude ore per year.

The design parameters of the underground mines at the Donskoy complex are given in table 12.

Table 12.—Design operational parameters of Donskoy complex underground mines (*10*)

	Molodezhnaya	Tsentral'naya
Crude ore production ..... 10^6 mt/yr ...	2	3-4
Cr_2O_3 content, %:		
Economic ore, av	51.5	50.0
Rich ore, no beneficiation	52.0	51.0
Poor ore, beneficiated	40.3	44.0
Concentrate	53.2	53.2
Tailings	15.5	15.5
Economic ore, no beneficiation required ..... % ..	95	50
Capital investment ..... 10^6 rubles ...	93.7	165.5

BENEFICIATION

There were three chromite concentrators in operation in the U.S.S.R. in 1934. The recovery efficiency of these plants (all in the Urals) is shown in table 13, which also provides some insight into the grade of ore produced by the mines feeding these concentrators.

A mill at the Khabarnyy deposit (**15**),[2] with an annual capacity of 10,000 to 15,000 mt of concentrate, was put into operation in 1936. Only about a third of Soviet total output of chromite in 1937, or some 85,000 mt was of metallurgical-grade ore and concentrate, mostly from the Klyuchev and Khabarnyy deposits, and hand-sorted ore from the Verbly'uzhaya Gora deposit; the balance was mostly of chemical-grade materials. Since then Kempirsay production in Kazahkstan has greatly increased the total output of metallurgical-grade ore.

Table 13.—1934 chromite concentrator efficiency (*38*)

	Klyuchevskaya	Upper Nevinskaya	Gologorskaya
Ore processing ..... mt/d ..	160	35	6.5
Cr_2O_3 content, %:			
Ore	11-12	30	28-32
Concentrate	48	48	48
Recovery ..... % ..	80	80	95

[2]Boldface numerals in parentheses refer to locations on figure 2.

Marketable ores from the Donskoy Mining and Beneficiation Complex include those with a chromium oxide content of at least 45%, a maximum silica content of 10%, and a maximum lump size of 300 mm. Before the concentration plant was completed in 1974, ore preparation at Donskoy consisted of crushing rich ores to 300 mm, screening into 300- to 50-; 50- to 10-; and 10- to 0-mm sizes and hand picking of waste from the 300- to 50-mm size. These operations were carried out in the two crushing and sorting plants (drobil'no-sortirovochnaya fabrika—DSF) No. 1 (fig. 6) built in 1945 and renovated in 1960, and No. 2 built in 1965.

Most Donskoy complex ores are high enough in grade to be shipped with no beneficiation other than hand picking. Until 1974, the beneficiation method used in the Soviet Union consisted only of primary and secondary crushing, sorting, and classification. There were two crushing and sorting mills in operation at the Donskoy complex in 1983. The total design capacity of both plants is 2.5 million mt of feed per year, including 1.5 million mt of rich ore for crushing, screening, and hand picking and about 1 million mt for concentration.

The country's only other chromium ore beneficiation facility in 1983 consisted of a small crushing and sorting mill at Saranov, that simply classified ore into sizes once it was crushed.

Construction of a concentrator at Donskoy with a designed capacity of 950,000 mt of feed (688,000 mt of concentrate) per year was started in 1969 and completed in 1974. The plant was to beneficiate diluted ores accumulated in storage areas.

The plant flowsheet was developed by Uralmekhanobr (Ural Research and Designing Institute for Mechanical Concentration of Minerals) and calls for crushing of the initial ore to 80 mm; screening into 80- to 10-, 10- to 3-, and 3- to 0-mm fractions; washing of the 80- to 10-mm class on screens; concentration of the 80- to 10-mm class in heavy media, producing a coarse concentrate and tailings; jigging of the 10- to 3-mm, 3- to 0.5-mm classes in OMTK-4 and OMP-1A machines, with separation of concentrate middlings and waste tailings; and concentration of the 0.5- to 0.07-mm class on concentrating tables, producing concentrate and tailings. The middlings from concentration of the 80- to 10-mm class are to be subjected to closed cycle grinding to a coarseness of 10- to 0-mm and concentration by jigging together with the initial 10- to 0-mm class.

According to the plan, the middlings from jigging are ground in ball mills and, following desliming, are concentrated in spiral concentrators, the middlings from which are in turn sent to the concentrating tables (*9*, p. 12). From 1974 through 1978, 1,566,000 mt of feed materials with a chromium oxide content of 42.8% was processed, and 973,000 mt of concentrate with a chromium oxide content of 50.1% was obtained (*9*, p. 8). The concentrator recovery was only 72.7%. During the 1975-77 period the concentrator's marketable output increased by 110%, reaching 435,000 mt with an average content of about 50% in 1977. About 575,000 mt of concentrate, 30% over the 1977 level, was to be produced in 1980 with an average chromium oxide content of about 51%, but these targets were not met.

Currently, rich ores with a chromium oxide content of about 50% are being crushed, sized, and blended at Donskoy. Diluted ores containing 40% to 42% chromium oxide, obtained both from the open pits (current extraction) and from temporary storage, are being sent to the beneficiation plant. The recovery from ore into concentrate containing 48% to 51% of

Figure 6.—Central storehouse of DSF-1 crushing and sorting plant (*9*). DSF-1 is the chief chromite beneficiation facility in the Soviet Union.

Cr_2O_3 is 56% to 66%. Chromic oxide content in the tailings is 28% to 32%. Although the mill was put into operation in 1974, the planned production of concentrate has not been obtained (*24*). During mining operations, substandard ore containing 10% to 30% chromium oxide is stored in special areas.

There is one crushing and sorting mill in operation at Saranov Mine, which classifies ore into 100- to 10- and 10- to 0-mm sizes. After hand picking, the 100- to 10-mm size ore is shipped to consumers. The recovery of hand-picked ore is about 70%; 16% is 10- to 0-mm size and is dumped, and 14% is barren rock.

It was planned during the 1981-85 period to put into operation new facilities for production of 2.9 million mt per year of crude chromite and 2 million mt of concentrate, but the Soviet chromium industry continues to experience considerable difficulty in completing project on schedule.

CHROME ORE PRODUCTION

Before the Revolution

Commercial chromium ore production began in Russia in the middle of the 19th century. The source of chromite was the Urals where numerous small-scale deposits of high-grade chromite were mined. The first small chemical plant for processing of chromium ore, the Kamsk plant in the Urals, was constructed in 1850. Later the Khrompik, Polevsk, and other plants, also in the Urals, were put into operation. During the 1898-1900 period, the Russian Empire was the largest single producer of chromite. In 1900, its production of over 19,000 mt represented 36% of the world production, which was then over 53,000 mt. In 1913, Russia produced over 26,200 mt of marketable chromite, employing 478 workers (*1*, p. 44). While Russia appreciably increased its chromite output in the pre-World War I period, output growth was not as great as in other countries, particularly Zimbabwe (then Southern Rhodesia), Turkey, and New Caledonia.

By 1913, Russia's share of the world's production of chromite had fallen to 18.7%, although its tonnage output was 53% larger than in 1900. Russian mine owners did not develop their mines or equip them with modern machinery to keep pace with growth elsewhere.

1917 Through 1945

While production of chromite held up during most of the World War I period, chromium being an essential war commodity, it declined rapidly in the civil war years, and almost completely collapsed in 1922 and 1923. In each of these years, the total output of the Soviet mines amounted to less than 1,000 mt. In 1921, after a decision taken by the Tenth Party Congress, the New Economic Policy (NEP) was introduced. It tolerated private domestic trade and industry, although the State retained control of banks, foreign trade, large industry, natural resources, and transport.

With the reestablishment of private industry, production of chromite on a large scale was soon resumed and by 1925 reached prewar levels. Operations were started in the old mines, but many of them were equipped with modern machinery and supplied with an abundance of labor. Some 30 mines were put into actual operation. Production jumped from under 1,000 mt in 1923 to over 30,000 mt in 1925, increasing more rapidly than domestic demand, which amounted to but 25,000

mt in the 1925-26 period. Production was reduced during the next 2 yr, while export connections were being made. After that, rapid progress was made and the recorded U.S.S.R. chromite output reached 175,000 mt of marketable product in 1935, 186,000 mt in 1936, and nearly 210,000 mt in 1937.

Most of Soviet chromite output in this period came from the Urals. The most important producing mine, the Saranov Mine in the central Urals with output about 50,000 mt annually, started underground production in 1936, and until 1939 most of the chromite output was of nonmetallurgical grades. However, in 1937 the large metallurgical-grade Kempirsay deposits in Kazakhstan were discovered. With exploitation of Kempirsay field, Soviet output has become well balanced in respect to supplies of various grades. Prior to the discovery of Kempirsay, only about one-third of the national production was of metallurgical quality, the great bulk of the Urals output being suitable only for chemical or refractory purposes.

In 1939, of the total marketable chromite production of about 245,000 mt (planned production was 325,000 mt) the Urals produced over 187,000 mt and the balance (over 57,000 mt) was shipped from the Kempirsay region in Kazakhstan (*1*, p. 159). In 1941 the Urals produced 114,000 mt; the planned production was 220,000 mt. A 400,000-mt production was planned for 1942, when the Urals yielded about 40% of the output and Donskoy complex in Kazakhstan about 60%. By 1943 and 1944 the mining of small and medium size deposits in the Urals had nearly ceased and the total output was coming from two ore fields, from Saranov (17%) in the Urals and Kempirsay in the Kazkahstan. Distribution of 1941-45 production is given in table 14.

Tables 3 and 4 show Soviet production of marketable chromite, and its relation to world production, for the period 1895 through 1983.

Table 14.—Saranov deposit and Donsky complex mine production, 1941-45, thousand metric tons

	Saranov	Donskoy	Total
1941	114.0	146.0	260.0
1942	161.0	220.9	381.9
1943	118.0	311.8	419.8
1944	58.0	300.3	358.3
1945	67.0	294.2	361.2

Source: Gornyy Zhurnal (Mining Journal). Moscow, No. 5, 1985, p. 8.

1946 Through 1983

During the postwar period the Soviet Union's production of chromite and ferrochromium had been sufficient to supply all its domestic requirements; the country had also been both the major source of chromite for its Council of Mutual Economic Assistance (CMEA) partners and an important supplier to market economy countries. After the modernization of the Kempirsay open pits in the 1946-58 period, production, stimulated by export demand, continued to increase, and in 1958 it reached 1.3 million mt of marketable ore. In 1955 Soviet exports of chromite amounted to 12% of domestic production. It was planned to almost double production by 1965 and triple it by 1975, over that of 1958.

By 1954, the Soviet Union became the leading world chromite producer, and by 1970, with an estimated marketable output of 2.66 million mt, the U.S.S.R. accounted for over 37% of the world total output. According to the 5-yr plan for 1966-70, Soviet chromite output was to be increased by 30%. Chromite output by 1975 was expected to be about 18% higher than in 1970. Exports totaled 1.2 million mt in 1970, with about 90% going to non-Communist countries. Approximately half of the output was consumed or stockpiled in the Soviet Union.

The unofficial Soviet figure for 1970 marketable chromite output, 3 million mt (*7*) apparently was in reality crude ore, not marketable ore as suggested by some other western publications. Reference 7 also said that production in 1965 was 2.53 million mt. According to reference 26, output of crude chromite in 1970 was to be 3.4 million mt. It was planned to produce 4 million mt of crude ore in 1975.

The Donskoy mining administration at Khrom-Tau in Kazakhstan, which produced over 90% of the Soviet output in 1970, maintained its status as the only supplier of high-quality metallurgical ore in the U.S.S.R. This administration produced all grades of chromite from three open pits. The productivity of labor and equipment was below planned levels, and more than half the time the machinery employed in the open pits was idle (*22*). During the 1971-75 5-yr plan period, output of chromite increased by 9.7% (*9*, p. 5).

In the 1970's, although Soviet exports to CMEA nations remained fairly constant, exports to Western countries declined dramatically. Growth of Soviet production slowed in the first half of the 1970's and then virtually stagnated. Depletion of reserves of hard lumpy ore with 50% Cr_2O_3 that were amenable to surface mining at the Donskoy complex have forced the construction of the concentrator as well as the development of underground mines.

Under the 10th 5-yr plan, output of chromite in 1980 was scheduled to be 10% over the 1975 level. It was planned during this period to put into operation new facilities for production of 2.55 million mt/yr of crude ore. However, even the first stage of the underground Molodezhnaya Mine, with a capacity of 0.8 million mt/yr of crude ore, was not put into operation in 1980. Although chromite production was pressed energetically by the Government in the 1970's, actual accomplishments fell far short of goals. Expansion was delayed by difficulties in delivery of construction supplies, equipment, and materials. The result was that production increased from an estimated 2.86 million mt of marketable ore in 1975 to only 2.9 million mt in 1980. The number of industrial production personnel in 1977 was 1.5 times that in 1970, although the estimated production of marketable ore increased from 2.66 million mt in 1970 to 2.72 million mt in 1977 (*9*, p. 10) or only by 2%.

Soviet reported production of crude ore was 3.4 million mt in 1980 and decreased to 3.3 million mt in 1981. The 1981 production of marketable chromite was estimated at 2.9 million mt. The Donskoy complex produced 96% of Soviet output and was the only supplier of high-quality ore (*15*). Annual output of marketable chromite from the Saranov underground operation in the Urals is estimated now at about 175,000 mt.

The Donskoy complex covers 4,762 ha; the mining area is 350 ha, 585 ha is covered by overburden dumps, 100 ha by a reservoir, and 50 ha by the tailings. The rest of the area is taken up by the plant area, roads and rail lines, and reserves areas. Over 500 ha of land is occupied by worked out open pits. The total volume of worked out area is about 80 million m^3. Currently, the Donskoy chromite deposits are being mined by three open pits (Spornyy, Yuzhnyy, and the 40 Years of the Kazakh S.S.R.) and by the first stage of the Molodezhnaya underground mine. The first stage of Molodezhnaya was designed to have a capacity by 1985 of 800,000 mt/yr of crude chromite with Cr_2O_3 content of 45% to 51%; ultimate annual capacity of all stages of the Molodezhnaya Mine is to be 2 million mt. Development of the first stage of this mine was 5 yr behind schedule, and it probably would need 5 yr to bring it up to full extraction capacity of 800,000 mt/yr. The Donskoy complex employed over 4,280 persons in 1982 (*17*).

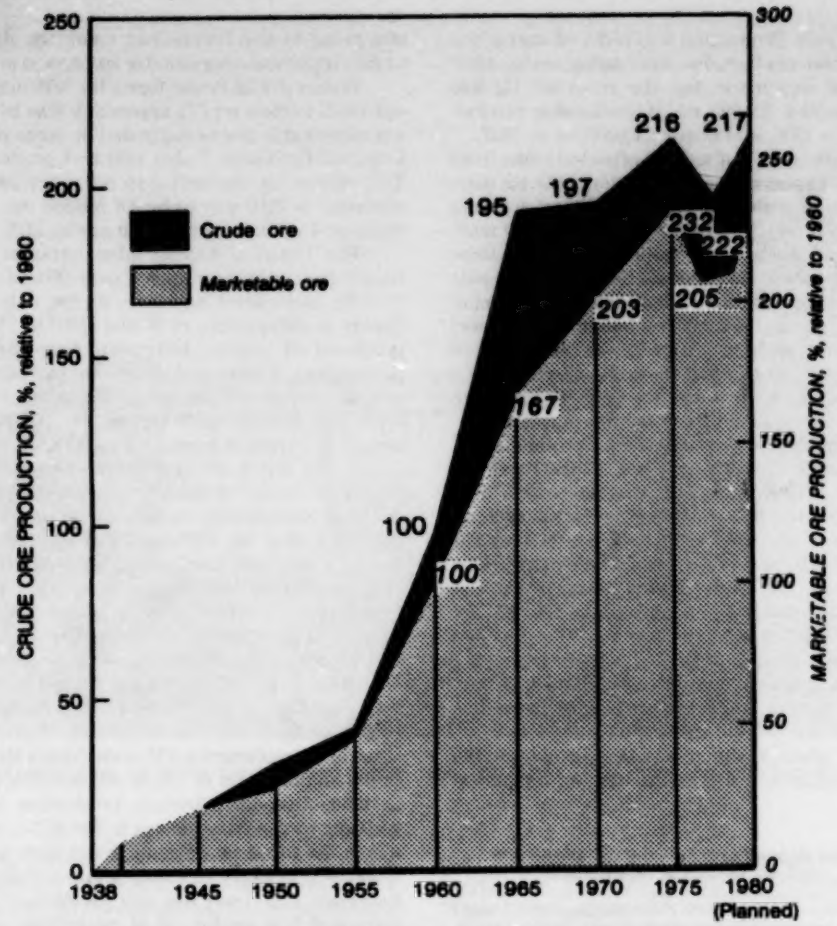

Figure 7.—Production of crude and marketable chromite at Donskoy Mining and Beneficiation Complex, 1938-80. (Modified and adapted from reference 9.)

Figure 7 summarizes the 1938-80 production of crude and marketable chromite at the Donskoy complex.

Soviet consumers of chromite are divided into metallurgical, refractory, and chemical industries. Metallurgical users consumed around 50% of the total chromite ore used in the Soviet Union in 1980.

Expansion Plans

Development of the first underground mine at the Donskoy complex, the Molodezhnaya Mine, began in 1973. It was planned to put into operation the first stage of this mine in 1978 (*8*). The 1975-80 5-yr plan again included provisions for completion of the first stage of the Molodezhnaya Mine, the first stage of a second underground mine at the Donskoy complex to be named the Tsentral'naya Mine, and No. 2 concentration mill. Actual production of the first stage of the Molodezhnaya Mine started only in March 1982 (*32*) and completion of the first stage of the Tsentral'naya Mine and concentration mill No. 2 was rescheduled for 1985. The deep part of the Millionnoye, Almaz-Zhemchuzhina, Pervomayskoye, and No. 21 deposits will be mined underground under the collective name of the Tsentral'naya Mine, at a rate of 4 million mt of crude ore per year. Expansion in the Soviet Union generally takes twice the time as in the West, if not longer.

According to the 5-yr plan for 1981-85, Soviet crude ore output was to be increased by over 11%, from 3.4 million mt in 1980 to 3.8 million mt in 1985. By 1985, output at the Donskoy complex was scheduled to increase by 14%, raising production to 3.6 million mt/yr of crude chrome ore (*16*). Under the 5-yr plan for 1981-85, new facilities for production of 2.9 million mt/yr of crude ore and 2 million mt of chromite concentrates were scheduled to be put into operation (*11*, p. 4).

In 1981, Soviet production dropped to 3.3 million mt of crude ore, and though it was planned to have risen back to 3.4 million mt in 1982, actual output was not more than 3.35 million mt. Open pit mining in the Soviet Union will significantly decline in the future. The use of low-grade ores that must be beneficiated and underground mining of deeper ore bodies will have an impact on the rate of production.

The reported production of crude and marketable chromium ores for 1901-37 and estimates for 1938-83 are shown in table 15, divided by grade.

Analysis of factual data from Soviet and other sources suggest that the chromium industry faces a number of serious problems. Growth in chromite production in the future will

Table 15.—Production of chromite and ferrochromium in the U.S.S.R., 1901-83,[1] thousand metric tons

Year	Chromite ore Marketable grade				Ferro-chromium[2]	Year	Chromite ore Marketable grade				Ferro-chromium[2]
	Crude	Metallur-gical	Refractory-chemical	Total			Crude	Metallur-gical	Refractory-chemical	Total	
1901	NA	NA	NA	22.17	NA	1943	°460	160	259.8	419.8	18
1902	NA	NA	NA	NA	NA	1944	°359	190	168.3	358.3	20
1903	NA	NA	NA	NA	NA	1945	400	240	121.2	361.2	20
1904	NA	NA	NA	NA	NA	1946	415	238	122	360	25
1905	NA	NA	NA	27.05	NA	1947	435	256	114	370	26
1906	NA	NA	NA	NA	NA	1948	450	260	125	385	28
1907	NA	NA	NA	NA	NA	1949	460	268	122	390	33
1908	NA	NA	NA	NA	NA	1950	500	280	130	410	39
1909	NA	NA	NA	NA	NA	1951	600	290	215	505	57
1910	NA	NA	NA	14.25	NA	1952	700	320	280	600	69
1911	NA	NA	NA	30.23	NA	1953	800	380	320	700	77
1912	NA	NA	NA	26.26	NA	1954	900	427	383	810	83
1913	NA	NA	NA	29.26	NA	1955	1,100	580	420	1,000	92
1914	NA	NA	NA	22.0	NA	1956	1,200	660	440	1,100	102
1915	NA	NA	NA	22.8	NA	1957	1,300	725	465	1,190	113
1916	NA	NA	NA	19.5	NA	1958	1,420	760	540	1,300	125
1917	NA	NA	NA	9.2	NA	1959	1,530	825	555	1,380	138
1918	NA	NA	NA	0	NA	1960	1,700	960	530	1,490	140
1919	NA	NA	NA	0	NA	1961	1,900	1,010	570	1,580	148
1920	NA	NA	NA	2.63	NA	1962	2,050	1,070	600	1,670	162
1921	NA	NA	NA	2.64	NA	1963	2,250	1,175	605	1,780	180
1922	NA	NA	NA	.94	NA	1964	2,450	1,280	610	1,890	195
1923	NA	NA	NA	.89	NA	1965	2,530	1,400	650	2,050	200
1924	NA	NA	NA	11.89	NA	1966	2,730	1,600	680	2,280	220
1925	NA	NA	NA	30.11	NA	1967	2,800	1,700	670	2,370	240
1926	NA	NA	NA	30.36	NA	1968	2,830	1,770	720	2,490	257
1927	NA	NA	NA	19.29	NA	1969	2,880	1,860	710	2,570	268
1928	NA	NA	NA	25.54	NA	1970	3,000	1,930	730	2,660	280
1929	NA	NA	NA	52.89	NA	1971	3,200	1,900	850	2,750	307
1930	NA	NA	NA	82.00	NA	1972	3,330	1,985	915	2,900	314
1931	94.1	NA	NA	87.00	NA	1973	3,350	2,100	900	3,000	324
1932	67.1	47	17.23	64.23	1.9	1974	3,380	2,120	920	3,040	332
1933	NA	66	51.67	117.67	2.2	1975	3,390	2,125	735	2,860	333
1934	129	72	43.00	115.00	7.7	1976	3,200	1,910	710	2,620	335
1935	184	76	99.00	175.00	12.6	1977	3,000	1,820	900	2,720	337
1936	227	78	108.00	186.00	19.3	1978	3,100	1,830	980	2,810	339
1937	217	85	124.70	209.70	20.2	1979	3,200	1,900	1,090	2,990	370
1938	250	87	123	230	22.2	1980	3,400	2,000	900	2,900	390
1939	263	93	151.5	244.5	23.7	1981	3,300	1,950	950	2,900	400
1940	°290	137	123	260	24	1983	3,350	2,000	940	2,940	415
1941	°290	120	140.0	260.0	22	1983	3,350	2,000	940	2,940	415
1942	°420	100	281.9	381.9	14						

NA Not available. °Estimated. [1]Reported, 1901-37; estimated, 1938-83.

[2]Electric furnace production. Although there are no definitive statistics on ferrochromium production prior to 1932, there are indications of production of at least small amounts of blast furnace ferrochromium as early as 1907.

Sources: References 6, 13, 21, 26, 31, 33-34.

be constrained by shortages of resources of rich ore for surface mining, resulting in the need for concentration of lower grade ore and the development of underground mines. Future operations at underground mines will be accompanied by increasing rock pressures and ventilation and airconditioning problems. The Cr_2O_3 content of average run-of-mine ore presumably will continue to decline. This will increase the load on beneficiation facilities, which will need to have the capacity to process larger quantities of crude ore. For these reasons there are good grounds for questioning the chances of success in meeting the 1981-85 plan for chromite production.

FERROCHROMIUM TECHNOLOGY AND PRODUCTION

Technology

Chromium is indispensable to any industrially developed country because there is no substitute for it in stainless steels and high-temperature-resisting superalloys. The largest Soviet use of chromium is the manufacture of stainless steels and corrosion-resistant alloys. There are four different types of Soviet chromium steels: those containing relatively low percentages of chromium, 3% and less; those containing between 3% and about 10% chromium; steels containing from approximately 14% to 20% chromium; and steels of still higher chromium contents. Soviet special and stainless steels contain from 12% to 30% chromium and on the average contain 20%. Production of these steels accounts for more than half of total Soviet consumption of chromium. There are also important applications of chromium in the refractory and chemical industries and for many of these uses, no suitable substitutes have been found.

Soviet industry manufactures 30 grades of chromium metal and its alloys and 3 grades of intermediate alloys used in the production of carbon-free and medium-carbon ferrochromium.

For metallurgical application, chromium is chiefly used in alloy form, principally combined with iron, as ferro-

Table 16.—Composition of Soviet ferrochromium, percent (29)

Type and official grade code	Cr, not less than	N, not less than	C		Other elements, not more than				
			Min	Max	Si			P	S
					Low	Med	High		
Carbon free:									
Khr 0000	65	NA	NAp	0.06	1.0	1.5	NA	0.06	0.04
Khr 000	65	NA	0.07	.10					
Khr 00	60	NA	.11	.15					
Low carbon:									
Khr 0	60	NA	.16	.25	1.5	2.0	3.0	.06	.04
Khr 01	60	NA	.26	.50					
Medium carbon:									
Khr 1	60	NA	.51	1.0	NA	2.5	3.0	.10	.04
Khr 2	60	NA	1.1	2.0					
Khr 3	60	NA	2.1	4.0					
High carbon:									
Khr 4	65	NA	4.1	6.5	2.0	3.0	5.0	.07	.04
Khr 6	65	NA	6.6	8.0					
Special carbon free:									
Khrb 1	70	NA	NAp	.04	NAp	.8	NAp	.02	.03
Khrb 2	70	NA	NAp	.04	NAp	1.0	NAp	.03	.03
Nitrided: Khrn 1	70	0.90	NAp	.05	NAp	1.0	NAp	.03	.03

NA Not available. NAp Not applicable.

chromium. In the U.S.S.R., ferrochromium alloys, as well as chromium metal, are made in a number of commercial grades. According to GOST (All-Union State Standard), the Soviet Union produces 13 grades (table 16) of ferrochromium differing mainly in their carbon content. The chromium content of an alloy is determined mainly by the natural chromium-iron ratio in chromium ores, but also depends upon the process of production of the alloy.

Three grades of metallic chromium conforming to GOST, are produced in the U.S.S.R., these are summarized in table 17.

Table 17.—Composition of Soviet chromium metal, percent (29, p. 166)

Grade	Cr, not less than	Not more than						
		Fe	Al	Si	Cu	C	P	S
Kh 0	98.5	0.6	0.5	0.4	0.06	0.03	0.02	0.02
Kh 1	98.0	.8	.7	.5	.06	.05	.03	.04
Kh 2	97.0	1.2	.8	.5	.1	.06	.05	.05

The production of ferrochromium from chromite by carbon reduction requires high temperatures, and is commonly carried out in submerged-arc electric furnaces. In the Soviet Union, high-carbon ferrochromium is smelted in 7,500- to 9,000-kW electric furnaces. Chromite and fluxes are crushed to 50 to 60 mm. High-carbon ferrochromium is smelted continuously, and the charge materials are fed in small portions, keeping the furnace full, while alloy and slag are tapped at regular intervals. Losses of chromium in the production of ferrochromium range from 8% to 10%.

Low-carbon and carbon-free ferrochromium are smelted in electric furnaces lined with magnesite brick. Graphite or pressed electrodes are used. The smelting charge consists of chromite, ferrochromium-silicon, and lime. Chromite is used in lumps not larger than 50 mm and having the least possible silica content. Phosphorus content should not exceed 0.06%. Crushed or granulated ferrochromium-silicon not larger than 10 to 15 mm is added to the melt. Chromium losses during the production stage are from 15% to 17%. In all Soviet plants, ferrochromium is cast into cast-iron or steel molds, and after it has cooled, it is crushed in jaw crushers and packed.

In the current Soviet metallurgical practice, at least some chromite is processed first to produce ferrochromium-silicon (ferrosilicochromium) and this intermediate material is further processed to produce the various grades of refined ferrochromium. Table 18 provides details on the composition of ferrochromium-silicons produced and used to make certain grades of the refined ferrochromium described in table 16.

Table 18.—Composition of selected Soviet ferrochromium-silicon used in producing certain grades of ferrochromium, percent (29, p. 166)

Grade	Si		Cr		C	P
	Min	Max	Min	Max		
Khr 0000	51	53	27	29	<0.02	0.05
Khr 000	48	50	27	29	0.03-.06	.05
Khr 00	48	50	29	30	.03-.06	.05
Khr 0 and 01	43	46	32	34	<.20	.05
Khr 1 and 2	27	33	41	44	<.7	.05

Losses of chromium in the process of converting ferrochromium-silicon to refined ferrochromium amount to 4% to 5%. In all likelihood, production of ferrochromium-silicon is very largely dedicated to domestic refined ferrochromium production, although there were some small exports reported during the 1970's and there may have been additional, but almost assuredly small, unreported exports of this product.

In the Soviet Union, the aluminothermic method is used to produce metallic chromium and various chromium-containing alloys, but the chief method of production of high-purity chromium metal is electrolysis. Soviet sources claim that electrolytic chromium metal is cheaper and purer than that produced by the aluminothermic process. However, a drawback of electrolytic chromium metal is its high hydrogen and oxygen content.

In 1983, there were 15 electric furnace ferroalloy plants known to be in operation, including 6 that contributed to the production of total national ferrochromium production, which was estimated at 415,000 mt for that year. The ferrochromium producing plants were located at Aktyubinsk (44), Chelyabinsk (43), Klyuchev (42), Serov (41), Zaporozhye (46), Zestafoni (45), and Yermak (47). Other electric furnace ferroalloy plants, not producing ferrochromium, include facilities at the following locations: Chusov, Izhevsk, Moscow Hard Alloy Complex, Nikopol', Novokuznetsk, Novolipetsk, Satkin, and Stakhanov.

Specifics on facilities producing ferrochromium-silicon and chromium metal are not available; it may be that the production of these materials is confined to the plants noted as ferrochromium producers, but this is by no means assured.

Production

The ferroalloys known to have been produced in prerevolutionary Russia are ferromanganese, spiegeleisen, and low-grade ferrosilicon. Ferromanganese and spiegeleisen were produced in blast furnaces of Ukrainian steel plants. Electric furnace plants at Satka and Porogi in the Urals produced ferrosilicon with 30% to 45% Si. The annual production capacity of the Satka plant was 5,000 mt. There is evidence of ferrochromium production in charcoal blast furnaces in the Urals as early as 1907, but no statistical data are available on this output or any other ferrochromium production in prerevolutionary Russia. Moreover there is no authoritative mention of ferrochromium production through the civil war period or the time of the New Economic Policy period.

The first electric furnace production of ferrochromium started in 1931 at the Chelyabinsk ferroalloy plant in the Urals; by 1933, the Zaporozhye ferroalloy plant in the Ukraine was operating. Production of ferrochromium in the U.S.S.R. increased from 1,900 mt in 1932 to 20,000 mt in 1937. Generally speaking, the Soviets have published little on ferrochromium production from a quantitative viewpoint. The Government of the Soviet Union has regarded statistics on the production of ferrochromium for any year subsequent to 1937 as a state secret. Therefore, for those years up to and including 1937 for which published Soviet statistics are available, the data series on ferrochromium production were based on published data as shown in table 15. From these published data, figures on ferrochromium production were developed using available published information on planned growth and actual achievements given in percent. Expansion of ferroalloy plant capacity was emphasized in the third 5-yr plan (1938-42), which was called the "Five-Year Plan for Special Steels," but actual production of ferroalloys was reportedly much below planned (but unspecified) goals.

The outbreak of World War II immediately aggravated the shortage of skilled labor and the general shortage of all labor continued through the war. Only 15% to 20% of the original workers and engineers remained at the mining and smelting operations, the balance being drafted into the armed forces (*3*). Military actions brought some chromium industry operations to a halt. The Zaporozhye alloy plant in the Ukraine was put out of action completely. However, the first sections of the Aktyubinsk and Klyuchev ferroalloy plants, which started with production of ferrochromium, were put into operation in 1942-43.

Ferrochromium production declined during the war and output of ferrochromium in 1945 was below that of 1940, despite the increased demand during the war period. The difference between production and demand was made up by lend-lease supplies provided by the United States, the United Kingdom, and Canada. According to reference 36, the 1940 level of ferroalloys production at the Zaporozhye plant in the Ukraine was again reached only in 1951. The average losses of chromium at this plant decreased from 26.6% in 1951 to 18.6% in 1958 (*2*).

Production of ferrochromium in the Soviet Union increased, compared with the 1940 level, 4% by 1946, 63% by 1950, and by 280% by 1955 (*4*). In 1955, output of total ferroalloys at the Aktyubinsk plant rose by 92% as compared with the 1950 level, but recovery of chromium in the product did not increase by the 2% to 3% called for by plan targets (*14*). Production of ferrochromium started at the newly constructed Serov plant in the Sverdlovsk Oblast', Urals, in 1958.

During the 1958-67 10-yr period, the Aktyubinsk ferroalloy plant in Kazakshtan increased production of ferroalloys by 59.6%. Recovery of chromium in ferrochromium grew from 77.9% of that in feed materials in 1958 to 86% in 1967 (*35*). This plant is the third largest ferroalloy works in the U.S.S.R. It specializes in the production of chromium ferroalloys, as does the Serov plant in the Urals. Electric furnaces and other equipment at the Aktyubinsk ferroalloy plant were idle for some part of working time during the 1965-69 period (*22*).

It was envisaged that by 1970 the output of ferroalloys in the U.S.S.R. should grow by 160% over that of 1960 (*19*), but during this period Soviet production of ferroalloys was much below the planned targets. It is estimated that Soviet production of ferrochromium increased from 138,000 mt in 1959 to only 280,000 mt in 1970.

During the 1971-80 period, the Soviets planned to bring on-stream new ferrochromium production facilities. They intended to reach an agreement with U.S. companies on the construction of ferroalloy plants, with repayments in production, and were also negotiating similar projects with several West European and Japanese companies. These plans were not fulfilled, but nevertheless Soviet production of ferroalloys increased from 3.5 million mt in 1970 to 4.6 million mt in 1980, or by 31% (*30*). Estimated output of ferrochromium increased from 280,000 mt in 1970 to 390,000 mt in 1980, or by 39%.

The electric furnace ferrosilicon industry is reportedly the largest of the ferroalloy industries in the U.S.S.R. More than a half of the electrical power used by ferroalloy plants is consumed by this industry. Reportedly, the ferrochromium industry is the second largest of the Soviet ferroalloy industries. More than one-third of all the electrical energy used by ferroalloy plants is consumed in the manufacture of chromium ferroalloys in electric furnaces.

Metallurgical users consumed about 50% of the total production of the Donskoy Mining and Beneficiation Complex (*21*). The Aktyubinsk ferroalloys and Aktyubinsk chromium chemical plants used only 16.4% of the total crude chromite production of the Donskoy complex in 1982 (*23*). The renovation and technical retooling of the Aktyubinsk ferroalloys plant are envisaged. The marketable ores of the Donskoy complex are shipped to 16 to 18 consuming works as well as for exports (*12*).

Large losses of chromium from that contained in marketable ores are suffered in current ferrochromium production processes; the losses may reach 25% in producing high carbon types and 8% to 10% in producing ferrochromium-silicon (*21*). For example, in 1976-79 recovery of chromium in low-carbon ferrochromium production decreased by 7.2%, in carbon-free grade by 3.2%, and in high carbon ferrochromium by 2.2% (*21*).

The reported Soviet production of ferrochrome for 1932-37 and estimated production for 1938-83 are shown in table 15.

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CHAPTER 4.—FOREIGN TRADE (ORE, CONCENTRATE, AND FERROCHROMIUM)

The U.S.S.R. is a leading world exporter of high-grade chromite; in recent years ranked second after the Republic of South Africa or third after that nation and Albania as an exporter of this product. With the startup of mining operations at Kempirsay, Soviet chromite exports from the 1960's to the present consisted largely of metallurgical grade lump ore. This is indirectly indicated by the fact that for most years, U.S. imports from the U.S.S.R. have been of a higher grade on a contained Cr_2O_3 basis than the average U.S. import.

Soviet exports of chromite started in 1926, 1 yr after chromium mine production reached pre-World War I levels.[1] The October Revolution in Russia and the civil war had destroyed much of the country's industrial infrastructure and dislocated prewar commercial operations including foreign trade. The potential for Soviet chromite exports during the period was further curtailed by initial hostility toward the new regime by Western governments followed by caution on the part of these governments toward involvement with that regime. This restraint was possible because of the growth of chromite supply sources elsewhere and because of reduced world demand during this period.

From 1926 to 1935, Soviet exports of chromite peaked at about 41,000 mt in 1932 and 1933. During the same period, imports of ferrochromium by the U.S.S.R., which lacked ferrochromium production facilities, rose from about 500 mt in 1927 to around 10,000 mt in 1933. Anticipating the startup of the country's first ferrochromium plant in 1936, the U.S.S.R. sharply curtailed both exports of ore and imports of ferrochromium in 1935, and in 1936 available data indicate a cessation of both exports of chromite and imports of ferrochromium. It is possible that some ferrochromium may have been imported by the U.S.S.R. during World War II and the immediate postwar period although no statistics are available.[2] Presumably, in 1936 the Soviet steel industry was consuming all of the available domestic output of chromite.

During the 1927-35 period, Europe was the major consumer of Soviet chromite and chromates. According to published Soviet data, about 4,500 mt of ore was shipped to the United States in 1935.[3]

Table 19 provides an overview of Soviet export and import of chromium materials for the 1926-83 period. There is little if any official Soviet statistical evidence concerning trade in chromium products from 1936 to 1941.

Chromite exports resumed in 1942, almost entirely to the United States presumably as backhaul freight within the context of the lend-lease agreements during World War II. Actual deliveries of chromite to the United States, were begun in 1942 and continued beyond the end of the war until 1950. These shipments were suspended from 1951 to 1958; a period covering both the Korean war and the height of the cold war.

Sales of chromite to the United States however, were again resumed in 1959, and in the late 1960's to mid-1970's the United States became a major recipient of Soviet chromite. United States imports declined from a high of over 425,000 mt in 1970, to around 30,000 mt in 1982, and finally dropped to less than 500 mt in 1983. Table 20 provides details of Soviet chromite imports by the United States from 1942 through 1983. Soviet chromite exported to the United States in most years was largely high-grade ore for metallurgical use, although during some years refractory and chemical grades were also shipped. Apart from the United States, Europe has been the most significant consumer of Soviet chromite. Among the West European market economy countries, the

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[3]Second work cited in footnote 2.

Table 19.—U.S.S.R. exports and imports of chromite, chromium ferroalloys, and chromium chemicals, 1926-83, thousand metric tons (rounded)

Year	Export							Import
	Marketable chromite	Ferrochromium	Ferrochromium-silicon	Sodium bichromate	Potassium bichromate	Chromium trioxide	Chromium oxide, n.e.s.	Ferrochromium
1926	2.3	0	0	0	0	0	0	0
1927	3.0	0	0	0	0	0	0	.5
1928	5.4	0	0	[1]0.4	([1])	0	0	.6
1929	8.6	0	0	1.5	([1])	0	0	.6
1930	15.0	0	0	[1]1.1	([1])	0	0	2.2
1931	23.8	0	0	[1]1.9	([1])	0	0	4.2
1932	41.5	0	0	[1]1.9	([1])	0	0	4.0
1933	41.0	0	0	[1]2.6	([1])	0	0	9.6
1934	36.5	0	0	NA	NA	0	0	5.3
1935	11.5	0	0	[1]2.7	([1])	0	0	2.9
1936	0	0	NA	NA	NA	NA	NA	0
1937	0	0	NA	NA	NA	NA	NA	0
1938	0	0	NA	[1]1.0	([1])	NA	NA	0
1939	0	0	NA	[1]2	([1])	NA	NA	0
1940	37.0	0	NA	[1]2	([1])	NA	NA	0
1941	NA	NA	NA	NA	NA	NA	NA	0
1942	[2]27.3	NA	NA	NA	NA	NA	NA	0
1943	[2]90.6	NA	NA	NA	NA	NA	NA	0
1944	[2]101.9	NA	NA	NA	NA	NA	NA	0
1945	[2]160.8	NA	NA	NA	NA	NA	NA	0
1946	122.0	0	NA	.1	NA	NA	NA	0
1947	286.0	0	NA	0	NA	NA	NA	0
1948	357.0	0	NA	.1	NA	NA	NA	0
1949	98.0	0	NA	.2	NA	NA	NA	0
1950	96.0	0	NA	.2	NA	NA	NA	0
1951	31.0	0	NA	.5	NA	NA	NA	0
1952	26.0	0	NA	.4	NA	NA	NA	0
1953	58.0	0	NA	.5	NA	NA	NA	0
1954	44.0	0	NA	1.1	NA	NA	NA	0
1955	158.0	NA	NA	0.7	NA	NA	NA	0
1956	219.0	NA	NA	0	0	0	NA	0
1957	259.0	16.9	NA	0	0	0	NA	0
1958	215.0	20.0	NA	0	0	0	NA	0
1959	272.0	18.7	NA	0	0	0	NA	0
1960	427.0	22.2	NA	0	0	0	NA	0
1961	438.0	21.7	NA	0	0	0	NA	0
1962	472.0	16.0	NA	[3].5	[3].2	0	NA	0
1963	567.0	14.1	NA	6.5	.3	.6	NA	0
1964	663.0	15.4	NA	9.4	.8	1.4	NA	0
1965	748.0	24.8	NA	16.7	.4	1.9	NA	0
1966	920.0	29.8	NA	26.0	NA	2.1	NA	0
1967	1,030.0	31.0	NA	29.0	NA	2.2	NA	0
1968	1,048.0	33.3	NA	25.8	4.4	4.2	NA	0
1969	1,144.0	37.8	NA	28.7	5.3	5.0	NA	0
1970	1,200.0	44.8	3.0	34.3	6.8	5.3	NA	0
1971	1,054.0	42.3	3.3	34.0	7.3	6.2	NA	0
1972	1,065.0	48.7	1.6	37.1	3.6	5.3	NA	0
1973	1,226.0	46.4	2.7	37.7	5.6	5.5	NA	0
1974	1,139.0	46.4	3.0	37.4	5.8	5.3	NA	0
1975	1,171.0	44.6	1.1	34.4	5.6	5.2	NA	0
1976	975.0	48.8	1.5	38.2	5.7	6.2	NA	0
1977	677.0	[e]44.4	.2	36.3	5.7	5.5	NA	0
1978	738.0	[e]44.8	2.6	35.1	5.6	5.4	3.2	0
1979	775.0	[e]35.7	.9	41.2	5.4	5.8	3.2	0
1980	[4]567.0	[e]41.6	.7	34.8	6.5	5.8	3.5	0
1981	[4]567.0	[e]48.0	[5].5	35.3	5.5	5.2	3.2	0
1982	[4]561.0	[e]51.0	[5]1.3	37.3	6.1	5.5	3.6	0
1983	[4]496.0	[e]49.4	[5]1.3	36.7	5.7	5.4	1.9	0

[e]Estimated (based primarily on Soviet reported value of ferrochromium exports).

NA Not available.

[1]Potassium bichromate included with sodium bichromate in official sources.

[2]Exports not officially reported, data are reported imports by the United States only.

[3]Partial data.

[4]Reportedly, small but undetermined quantities of chromite were shipped to the U.S.S.R. by Iran.

[5]Data reported as imports from official trade returns of receiving countries.

Source: Corresponding years of Vneshnyaya Torgovlya S.S.S.R. (Foreign Trade of the U.S.S.R.), Moscow.

Table 20.—U.S. imports for consumption of Soviet chromium ore, 1942-83

Year	Quantity,[1] 10^3 mt		U.S.S.R. share, %	
	Gross weight	Cr_2O_3 content	Gross weight	Cr_2O_3 content
1942	27.3	14.2	3.1	3.5
1943	90.6	43.7	11.0	12.0
1944	101.9	52.4	13.2	15.8
1945	160.8	78.4	19.1	21.6
1946	89.8	48.4	13.1	16.1
1947	240.5	123.4	24.0	28.0
1948	357.4	172.5	26.0	28.0
1949	97.2	46.7	8.9	9.6
1950	64.9	31.6	5.5	6.0
1951	0	0	NAp	NAp
1952	0	0	NAp	NAp
1953	0	0	NAp	NAp
1954	0	0	NAp	NAp
1955	0	0	NAp	NAp
1956	0	0	NAp	NAp
1957	0	0	NAp	NAp
1958	0	0	NAp	NAp
1959	57.3	27.7	4.1	4.6
1960	6.5	3.4	.05	.07
1961	17.6	8.8	1.5	1.7
1962	33.6	16.4	2.6	2.9
1963	173.9	84.6	13.7	15.4
1964	269.6	147.7	20.8	25.2
1965	219.1	121.2	16.0	19.5
1966	274.0	148.8	16.2	19.5
1967	271.2	149.7	24.1	29.0
1968	303.9	166.0	30.1	36.6
1969	288.5	156.0	28.7	34.0
1970	425.5	225.0	33.4	38.3
1971	278.5	148.8	25.0	27.8
1972	393.7	205.0	41.0	45.3
1973	219.5	108.0	26.0	29.0
1974	270.3	136.0	27.0	31.2
1975	316.6	158.0	28.0	31.3
1976	171.5	80.7	14.8	16.7
1977	72.6	35.4	6.0	7.2
1978	142.4	55.3	15.1	14.6
1979	226.8	88.9	24.0	24.0
1980	154.2	68.9	17.2	18.5
1981	100.7	43.5	12.3	13.0
1982	30.8	11.8	6.7	6.2
1983	([2])	NAp	NAp	NAp

NAp Not applicable. [1]Rounded. [2]Less than 500 mt.

NOTE.—Data are from Bureau of Mines Minerals Yearbook, v. I, corresponding years.

Table 21.—U.S.S.R. exports of chromium ore and concentrate by destination, 1960-83
thousand metric tons

Country	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
China	41	0	0	NA	0	NA	0	NA	NA	NA	NA	0
Czechoslovakia	53	48	66	44	15	33	49	45	60	70	89	106
France	48	55	66	60	70	88	99	100	90	95	114	89
Germany, Federal Republic of	77	84	50	51	70	76	100	150	108	124	131	117
German Democratic Republic	9	12	17	6	15	21	24	22	25	27	25	36
Hungary	0	8	14	16	11	11	9	11	11	6	13	21
Italy	4	13	17	20	24	45	49	52	59	53	33	60
Japan	61	65	80	77	95	123	145	165	160	138	124	85
Norway	NA	0	0	NA	0	NA	0	NA	NA	NA	NA	0
Poland	54	64	40	42	55	58	67	75	76	83	76	105
Sweden	58	56	53	49	72	67	89	110	123	139	133	150
United Kingdom	20	1	0	NA	0	NA	0	NA	NA	NA	NA	0
United States	0	32	69	192	236	223	289	280	326	387	410	275
Yugoslavia	NA	0	0	NA	0	NA	0	NA	NA	NA	NA	10
Other	2	0	0	3	0	3	0	20	10	22	52	0
Total	427	438	472	560	663	748	920	1,030	1,048	1,144	1,200	1,054
	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
China	0	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Czechoslovakia	97	104	107	131	115	131	126	128	131	130	146	116
France	71	95	59	95	93	57	18	17	23	8	0	0
Germany, Federal Republic of	107	180	96	156	147	62	47	24	0	0	0	0
German Democratic Republic	45	31	30	40	27	37	26	31	33	32	36	42
Hungary	17	10	18	17	17	17	17	17	15	15	14	17
Italy	54	65	48	27	35	5	5	NA	0	0	NA	NA
Japan	122	113	88	95	72	49	NA	NA	NA	30	76	78
Norway	0	21	0	NA	NA	NA	NA	NA	NA	NA	NA	NA
Poland	118	121	125	109	121	136	122	134	128	140	151	132
Sweden	127	180	182	140	138	7	36	77	10	30	21	20
United Kingdom	0	0	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
United States	285	281	317	270	118	77	223	234	99	76	11	0
Yugoslavia	22	25	47	61	70	85	88	80	64	88	80	64
Other	0	0	22	30	22	14	30	33	64	18	26	27
Total	1,065	1,226	1,139	1,171	975	677	738	775	567	567	561	496

NA Not available.

Source: Corresponding years of Vneshnyaya Torgovlya S.S.S.R. (Foreign Trade of the U.S.S.R.), Moscow.

Federal Republic of Germany, France, and Sweden have been the largest West European importers. The largest CMEA member importers were Poland and Czechoslovakia.

Total Soviet exports, as shown in table 21, declined from over 1.2 million mt in 1973 to just less than 0.5 million mt in 1983. This decline in sales was most pronounced in Western Europe where apparently the Federal Republic of Germany and France ceased imports of Soviet chromite in 1980 and 1982, respectively. Soviet chromite exports to Sweden declined from 182,000 mt in 1974 to 20,000 mt in 1983. On the other hand, Soviet exports to the CMEA members remained at previous or even increased levels. The trends of net import reliance on the Soviet Union are given in table 22.

Since 1960, the Soviet Union has been a substantial exporter of chromite to Japan. Exports rose from about 61,000 mt in 1960 to a high of 165,000 mt in 1967. However, from 1968 through 1977 Soviet exports to Japan gradually declined to around 49,000 mt. Although official Soviet exports statistics (Vneshnyaya Torgovlya S.S.S.R.—The Foreign Trade of the U.S.S.R.) did not report exports to Japan for 1978, 1979, and 1980, official Japanese trade statistics for these years indicated imports of chromite originating from the U.S.S.R. of 39,000, 25,000, and 16,000 mt respectively. Soviet exports to Japan from official trade returns for 1981 to 1983 show an upturn from 30,000 to 78,000 mt. Similarly, a number of other Organization for Economic Cooperation and Development country trade returns showed receipts of chromite of Soviet origin that were not reflected in official Soviet export statistics for the given years. Norway received Soviet chromite in every year from 1963 to 1977, with amounts ranging from 3,000 to 26,000 mt. From 1969 to 1971, Canada received 18,000 to 19,000 mt annually. Italy received small quantities of chromite in 1979, 1982, and 1983, as did Switzerland from 1969 to 1971. Apparently, Spain recorded a spot purchase in 1973, and no subsequent receipts have been determined. It is possible that some of these receipts may have been transshipments from designated receivers listed in table 21.

Table 22.—Import reliance by OECD West European and Soviet CMEA partners on Soviet chromite exports, for selected years, share of apparent consumption, percent

Year	OECD West European imports from U.S.S.R.	CMEA partner reliance on Soviet exports
1970	24	60
1975	22	58
1977	12	69
1978	11	57
1979	6	60
1980	6	67
1981	8	73

Source: Export data reported in Vneshnyaya Torgovlya S.S.S.R. (Foreign Trade of the U.S.S.R.), Moscow, for corresponding years and published data on production and trade from importing countries.

The U.S.S.R. had also registered substantial chromite exports to Yugoslavia between 1974 and 1983. Yugoslavia's domestic chromite resources have been largely depleted and imports of chromite from the Soviet Union and Albania provide necessary stocks to that country's ferroalloy and refractory industries.

Official Soviet trade returns have been used as the chief basis for statistical information provided in this chapter, especially that in tables 19, 21, and 23. When such data were

Table 23.—U.S.S.R. apparent exports of ferrochromium by destination, 1960-83, thousand metric tons

Country	1960	1961	1962	1963	1964	1965	1966	1967	1968	1969	1970	1971
Austria	2.20	0.80	0.60	0.40	0.50	0.70	1.00	2.20	2.90	3.85	3.50	2.88
Belgium-Luxembourg	NA	NA	NA	.40	3.60	1.50	.03	.30	[1].07	[1].01	[1].36	[1]1.22
Canada	0	0	0	0	0	1.50	0	0	0	0	0	0
Finland	1.28	.90	1.30	.10	.20	.50	.40	[1].45	.56	.33	.40	.84
France	0	0	0	0	0	0	0	0	0	0	0	0
Germany, Federal Republic of	2.50	3.80	2.80	.90	.90	3.00	3.00	2.90	2.90	3.15	3.03	3.28
Hungary	NA	NA	NA	0	4.00	4.40	5.40	6.90	7.40	6.83	7.35	7.73
Italy	NA	[1].05	[1].54	[1].29	[1].31	[1].20	[1].82	[1].93	[1].42	[1]1.83	[1]1.85	[1]1.34
Netherlands	[1]0	[1]0	[1].01	[1]0	[1]0	[1].05	[1]0	[1]0	[1]0	[1]0	[1]0	[1].37
North Korea	NA	NA	NA	0	1.40	1.50	1.90	1.90	1.90	2.19	2.51	2.49
Romania	NA	NA	NA	NA	0	4.00	5.70	6.60	6.80	7.77	9.56	9.81
Sweden	1.50	1.00	0	NA	0	1.80	2.50	.70	2.30	1.64	2.20	3.47
United Kingdom	NA	NA	NA	0	3.00	4.30	6.70	5.00	5.30	5.51	6.05	5.54
United States	0	0	0	0	0	.34	0	0	0	0	0	0
Other	14.72	15.15	10.75	12.01	1.49	1.01	2.55	3.12	2.75	4.69	7.99	3.33
Total	22.20	21.70	16.00	14.10	15.40	26.43	29.80	31.00	33.30	37.80	44.80	42.30
	1972	1973	1974	1975	1976	1977	1978	1979	1980	1981	1982	1983
Austria	5.55	4.64	5.24	4.08	5.21	[1]5.45	[1]5.86	[1]2.93	[1]2.80	[1]3.37	[1]4.93	[1]4.51
Belgium-Luxembourg	[1]3.48	[1]4.91	[1]3.77	[1]9.43	[1]6.28	[1]6.65	[1]5.17	[1]1.90	[1].99	[1]2.35	[1]3.80	[1]4.76
Canada	0	0	0	0	0	0	0	0	0	0	0	0
Finland	.36	.62	.64	.07	[1].05	[1]0	[1].86	0	0	0	0	0
France	0	0	[1].55	[1].17	[1].33	[1].52	[1]1.02	[1].22	.22	[1]1.60	[1]1.12	[1]1.56
Germany, Federal Republic of	3.09	2.30	3.81	3.43	3.97	[1]2.83	[1]3.80	1.73	[1]4.18	[1]4.41	[1]3.87	[1]2.37
Hungary	3.84	5.82	6.38	6.58	5.15	[1]5.91	[1]4.99	[1]5.85	[1]6.08	[1]5.18	[1]5.90	[2]6.20
Italy	[1]1.02	[1].82	[1].92	[1]1.33	[1]1.58	1.06	[1]1.23	[1].58	[1].09	0	[1].25	[1].31
Netherlands	[1].23	[1].75	[1].31	[1].24	[1]0	[1]0	[1]0	[1].03	[1]0	[1].37	[1].43	NA
North Korea	2.17	1.90	2.01	1.89	2.63	[1]1.70	[2]2.70	[2]4.00	[2]3.80	[2]3.10	[2]3.00	[2]3.50
Romania	9.67	8.23	7.62	7.46	10.08	[2]11.10	[2]12.00	[2]12.40	[2]13.40	[2]14.60	[2]16.10	[2]14.80
Sweden	3.11	2.56	2.83	2.89	3.03	[1]1.91	[1]2.58	[1]0	[1]0	[1]1.15	[1].75	[1]1.83
United Kingdom	5.38	7.34	4.62	3.43	5.96	[2]3.10	[1]2.30	[1].70	[1].30	[1].43	NA	NA
United States	0	0	0	0	0	0	0	0	0	0	0	0
Other	10.80	6.51	7.73	3.60	4.51	[2]4.17	[2]2.29	[2]5.36	[2]9.74	[2]11.44	[2]10.85	[2]9.56
Total	48.70	46.40	46.43	44.60	48.78	[2]44.40	[2]44.80	[2]35.70	[2]41.60	[2]48.00	[2]51.00	[2]49.40

[2]Estimated (based primarily on Soviet reported value of ferrochromium exports). NA Not available.

[1]Data reported as imports from official trade returns of receiving country.

Source: 1960-76 data are from corresponding years of Vneshnyaya Torgovlya S.S.S.R. (Foreign Trade of the U.S.S.R.), Moscow.

unavailable to complete a line series in tables 19 and 23, official foreign trade returns of the U.S.S.R.'s trade partners were used to help reconstruct the likely exports and/or imports by the U.S.S.R. for given years. In some cases (e.g., China), no trade data were available to indicate what the possible Soviet import-export was for a given year. It could be assumed that this information could be hidden in the trade residual designated as other (table 23), especially if the U.S.S.R. trade partner had a history of trading on a given commodity. In those cases where no official Soviet trade returns were provided, the official trade returns of the U.S.S.R.'s trade partner were used to obtain import data. It should be noted that for 1960-63 and 1972-74, a fairly large portion of Soviet ferrochromium exports could not be accounted for by designation. Presumably, most of the material in the other category was designated for shipment to centrally planned economy countries (China, Czechoslovakia, German Democratic Republic, Poland, Romania, etc.).

While Soviet chromium ore exports declined significantly in the late 1970's and early 1980's, exports of ferrochromium remained stable and showed an estimated moderate increase in 1981 and 1982. The U.S.S.R. stopped reporting exports of ferrochromium by weight and value after 1976 and reported exports in value only. Estimates for the years 1977 to 1983 were derived by linear analysis of ruble-metric ton ratios for earlier years (table 23). Although exports of ferrochromium appear stable, those to Western market countries declined from over 21,000 mt in 1972 to around 15,000 mt in 1982. Conversely, Soviet exports to CMEA member countries and North Korea rose for the same years; the largest export increase of ferrochromium to a CMEA-member nation was to Romania, which was around 16,000 mt in 1982 from about 10,000 mt in 1972. This sharp increase corresponds with the rapid and ambitious planned expansion of Romania's steel industry.

Since World War II, the government policies of CMEA member nations have promoted the development of heavy industry modeled on that of the U.S.S.R. Consequently, consumption of raw materials have risen over this period with the greatest deliveries coming from the Soviet Union. Chromite has also been shipped to the CMEA block from Albania, which was a member until 1961.

The decline in the total Soviet chromite exports, and, especially, exports to western Europe and the United States was a result of increased domestic demand, CMEA foreign trade requirements, and lower world market economy steel production.

Also, the decline in ore grades at the Donskoy Mining and Beneficiation Complex in Kazakhstan adversely affected the output of marketable chromite. Near depletion of the higher grades of ore amenable to surface mining and high losses during beneficiation and ferrochromium production, as well as the slow development of underground mines and new facilities (e.g., Molodezhnaya Mine and second concentrator), were among the main reasons for the declining output.[4]

Five-year incremental growth of total crude steel produc-

[4]Satybaldin, O. B. Prediozheniye po Ratsional'nomu Ispol'zovaniyu Khromitovykh Rud (A Proposal for the Rational Use of Chrome Ores). Paper in Kompleksnoye Ispol'zovaniye Mineral'nogo Syr'ya (Complex Utilization of Mineral Raw Materials), Alma-Ata, No. 5, Feb. 1982, pp. 63-67.

Table 24.—East European CMEA member nation's crude steel production, thousand metric tons

1965	28,391
1970	39,753
1975	53,286
1980	61,524

Sources: Officially published annual statistical handbooks for corresponding years of Bulgaria, Czechoslovakia, German Democratic Republic, Hungary, Poland, and Romania.

tion for CMEA countries is given in table 24, reflecting the increasing requirement in these countries for ferroalloy materials, including chromite and ferrochromium.

External market forces played a lesser role than the problems of domestic mining and CMEA industry requirements. The availability of large quantities of Albanian and South African ore in the world market in the 1970's and 1980's, as well as the increasing use of the argon-oxygen decarburization (AOD) process, a process that allows the efficient use of high carbon ferrochromium produced from lower grades of chromite ore, satisfied western market requirement at this time. The AOD process began to gain acceptance after the establishment of United Nations sanctions against Southern Rhodesian (Zimbabwean) exports, including that country's high-grade ore. Also, traditional western consumers shifted their chromium import patterns from chromite to ferrochromium from producing areas that have lower energy costs factored into the price of the commodity. The shift from chromite to ferrochromium was also occasioned by the resultant reduction of transport costs.

It is unlikely that increased production from the new mining facilities at Kempirsay will have any significant impact on the already oversupplied world chromium market, affected by the 1979 to 1982 depression in the steel industry. Although the export-import policy set by Soviet central planning authorities is not guided by routine market conditions, the chief consideration being to earn sufficient hard currency to be able to import Western technology and goods, a market must exist before Soviet chromite can be sold.

CHAPTER 5.—CONSUMPTION AND STOCKPILING

ORE AND CONCENTRATE

Metallurgical Use (Including Refractories)

The primary consumer of chromium ore and concentrates in the U.S.S.R. is the metallurgical sector, including refractories. In 1980, the Ministry of Ferrous Industry designated substantial amounts of chromite and concentrates produced in that year for metallurgical use;[1] this amounted to about 1.4 million mt. The total consumption of chromite from 1949 through 1983 (table 25) shows an almost uninterrupted rate of increase. The trend follows the post-World War II reconstruction and growth rate of Soviet heavy industry. However, the rate of consumption of chromite appeared to have slowed in the late 1970's and stagnated in the early 1980's when productivity and production of iron and steel declined.

Significant problems have arisen in transporting ore to consumers; losses of about 0.5% of the total annual production of ore and concentrate occurred each year during transportation.[2]

Chemical Use

About 26% of the total chromite produced for domestic consumption in 1980 was allocated to the chemical industries.[3] In the chemical industry the major portion of the chromite is used for the manufacture of sodium monochromate. Losses of chromite during this production stage are great, and tend toward approximately 25%.

[1]Obogoshcheniye Rud (Ore Dressing). Leningrad, No. 3, 1981, p. 16.

[2]Satybaldin, O. B. Predlozhniye po Ratsional'nomu Ispol'zovaniyu Khromitovykh Rud (A Proposal for the Rational Use of Chrome Ores). Paper in Kompleksnoye Ispol'zovaniye Mineral'nogo Syr'ya (Complex Utilization of Mineral Raw Materials), Alma-Ata, No. 5, Feb. 1982, pp. 63-67.

[3]Work cited in footnote 1.

Table 25.—U.S.S.R. nonadditive consumption (including stockpiling) of chromite and ferrochromium (estimated),[1] thousand metric tons (rounded)

Year	Chromium	Ferrochromium	Year	Chromium	Ferrochromium	Year	Chromium	Ferrochromium	Year	Chromium	Ferrochromium	Year	Chromium	Ferrochromium
1924	11.9	0.0	1936	186.6	19.3	1948	28.0	28.0	1960	1,063.0	117.8	1972	1,835.0	265.3
1925	30.1	.0	1937	209.7	20.0	1949	292.0	33.0	1961	1,142.0	126.3	1973	1,774.0	277.6
1926	28.1	.0	1938	230.0	22.2	1950	314.0	39.0	1962	1,198.0	146.0	1974	1,901.0	285.6
1927	16.3	.5	1939	244.0	23.7	1951	474.0	57.0	1963	1,213.0	165.0	1975	1,689.0	288.4
1928	20.1	.6	1940	223.0	24.0	1952	574.0	69.0	1964	1,227.0	179.6	1976	1,645.0	286.2
1929	44.3	.6	1941	NA	22.0	1953	642.0	77.0	1965	1,302.0	175.2	1977	2,043.0	293.6
1930	67.0	2.2	1942	354.6	14.0	1954	766.0	83.0	1966	1,360.0	190.2	1978	2,072.0	291.1
1931	130.0	4.2	1943	329.2	18.0	1955	842.0	91.0	1967	1,340.0	209.0	1979	2,215.0	334.3
1932	22.7	5.9	1944	256.4	20.0	1956	881.0	102.0	1968	1,442.0	223.7	1980	2,333.0	348.4
1933	76.6	11.8	1945	200.4	20.0	1957	931.0	96.1	1969	1,426.0	230.2	1981	2,333.0	352.0
1934	78.5	13.0	1946	238.0	25.0	1958	1,085.0	105.0	1970	1,460.0	235.2	1982	2,379.0	365.0
1935	163.5	15.5	1947	84.0	26.0	1959	1,108.0	119.4	1971	1,696.0	264.7	1983	2,444.0	265.6

NA Not available.

[1]Data presented for chromite represent calculated apparent consumption of chromite for the production of ferrochromium chromium-based refractories and chromium chemicals, while those for ferrochromium represent calculated apparent consumption of that ferroalloy for steel production. Thus, data are not additive.

In the Soviet chemical industry, defective and/or imperfect production processes have resulted in the formation of large quantities of slimes and slurries containing up to 12% Cr_2O_3. These slimes and slurries are produced at a rate of 2 to 2.2 mt per metric ton of usable sodium monochromate products. This situation poses not only a loss to the economy but also a threat to health and the environment in that large land areas were designated for holding ponds to contain chromium wastes. To date a number of solutions have been studied to alleviate the situation; they included the use of chromium-containing slurries and other wastes for the production of ferrochromium and the substitution of ferrochromium for chromite as a raw material for sodium monochromate production.[4]

FERROCHROMIUM

The country's principal consumer of chromite has been the ferroalloys sector of the steel industry (Ministry of Ferrous Metallurgy). Because ferrochromium is a nonsubstitutable ingredient in the production of a wide variety of high-temperature and stainless steels, its consumption grew at a higher rate than the U.S.S.R.'s crude steel output (table 26).

Problems relative to the efficient use of chromite within the ferroalloys sector are also serious. Roughly 20% of the chromium in chromite consumed during the production of chromium ferroalloys is lost annually.[5] Of this amount, about 60% is lost in slags, flue dust, and scrap; the remaining loss is unaccounted for. Dated and inefficient technology is at least partly responsible for this situation. The Aktyubinsk ferroalloys plant, built during World War II as a major ferrochromium producing facility, has not undergone major renovation. Production technology has been at a very low level and, according to Soviet sources, "irrational" priorities assigned to this plant also have resulted in low efficiency.[6]

From 1976 to 1979, greater amounts of lower grade ore have been used. The Cr_2O_3 content of ore used in ferrochromium production decreased by 2% to 3%, even with increasing ore concentration owing, in part, to a decreasing Cr_2O_3-FeO ratio. Also, the chromium content of ferroalloys from 1976 to 1979 declined by 7.2% for low-carbon ferrochromium, 3.2% for carbon-free ferrochromium, and 2.2% for high-carbon grades of ferrochromium. The poor ore quality led to higher losses in slag and increased energy costs.

Although the U.S.S.R. has maintained stockpiles of strategic materials, including minerals, since the Second World War, stockpiling policy and quantitative information covering strategic stocks are classified under the U.S.S.R.'s State Secrets legislation. Owing to the relative abundance and availability of chromium, it is not likely that major stockpiles are maintained outside industrial facilities such as concentrators and ferroalloy plants.

Table 26.—U.S.S.R. ferrochromium consumption and crude steel production, thousand metric tons

	Consumption	Production
1960	118	65,260
1970	235	112,948
1975	288	132,278
1980	348	147,941

NOTE.—Production data are from corresponding years of Navodnoye Khozyaistvo S.S.S.R. (The National Economy of the U.S.S.R.).

[4]Page 64 of work cited in footnote 2.
[5]Page 64 of work cited in footnote 2.
[6]Page 65 of work cited in footnote 2.

CHAPTER 6.—INFRASTRUCTURE

MINERAL POLICY

The underlying goal of the Soviet mining and mineral economy is maximum self-sufficiency. The discipline of the market is nonexistent and relative values are assigned administratively and, hence with overriding political considerations. At the highest level, the Central Committee of the C.P.S.U., and the Council of Ministers through the U.S.S.R. State Planning Committee (Gosplan) are responsible for setting all industry production and performance goals for annual, as well as 5-yr plans. Specific goals are established by Gosplan's Department of Ferrous Metallurgy, and subsequently transmitted to the U.S.S.R. Ministry of Ferrous Industry for implementation at mines, plants, and other facilities.[1] The dual practices of gauging production quantitatively in terms of tonnage, and on a ruble value basis have had a negative impact on both the chromium industry and the Soviet economy in general. The former practice allows a high waste of resources, in that enterprises tend to produce to the assigned tonnage-output level called for by the plan and not necessarily to the specific needs and specifications required by the end user. Therefore, the output that cannot be usefully consumed is either scrapped, or wasted. The ruble values assigned to industrial products by the State do not necessarily reflect real relative costs, but often represent priorities set within the centrally planned economy structure. In some cases chromite mining and other operations would not necessarily be viewed as economically feasible in market economy countries.

The overwhelmingly dominant share of currently operating Soviet chromite mines are administered by the Donskoy Mining and Beneficiation Complex in Khrom-Tau. The complex administers all of the workings in the Kempirsay area as well as two crushers and a beneficiation plant. The area is linked to the city of Orsk by the Orsk-Kandagach railway and from there to the industrial centers at Aktyubinsk, Chelyabinsk, Magnitogorsk, and to Rostov on the Don in the Black Sea area and to processing areas in Georgia and the Ukraine. The much smaller Saranov deposit located in the northern part of the Urals is closer to the major industrial hubs of the U.S.S.R. (see figure 2). Figure 8 provides an overview of the organizational-administrative structure of the Soviet chromium industry.

[1]Directory of Soviet Officials: National Organization. Aug. 1983, pp. 62-73; NTIS CR 83-13841.

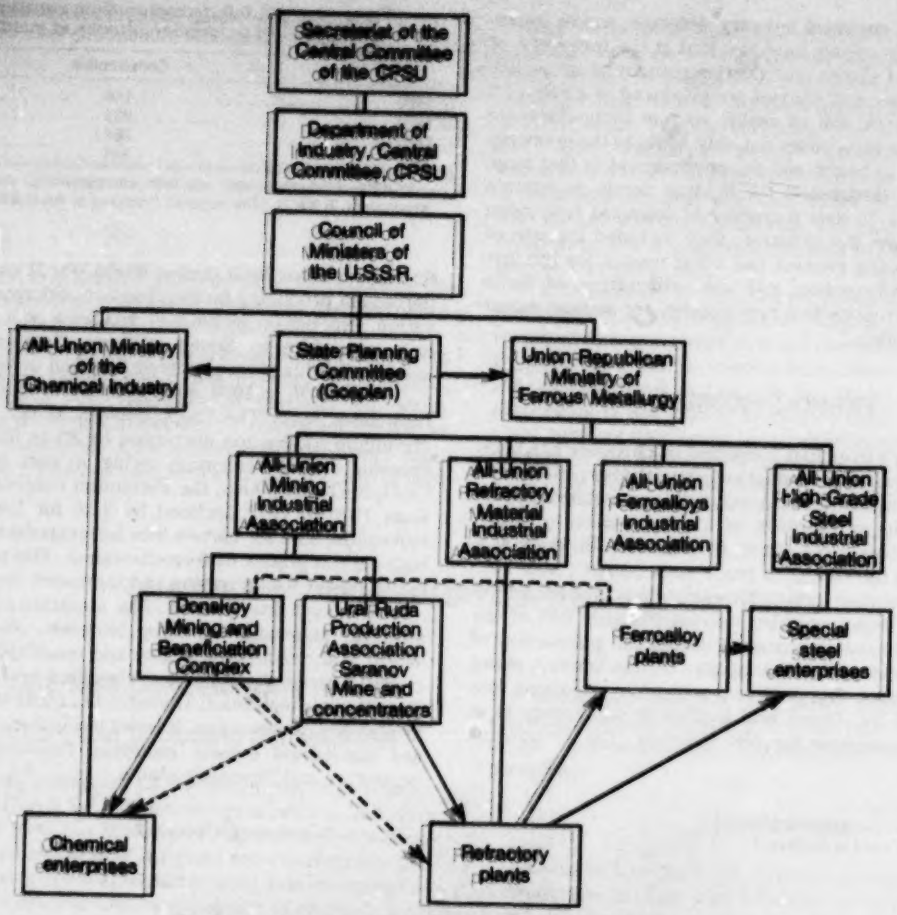
Secretariat of the Central Committee of the CPSU
Department of Industry, Central Committee, CPSU
Council of Ministers of the U.S.S.R.
All-Union Ministry of the Chemical Industry
State Planning Committee (Gosplan)
Union Republican Ministry of Ferrous Metallurgy
All-Union Mining Industrial Association
All-Union Refractory Material Industrial Association
All-Union Ferroalloys Industrial Association
All-Union High-Grade Steel Industrial Association
Donskoy Mining and Beneficiation Complex
Ural Ruda Production Association Saranov Mine and concentrators
Ferroalloy plants
Special steel enterprises
Chemical enterprises
Refractory plants

Figure 8.—Organization of the Soviet chromium industry.

PRODUCTION COST

In the case of chromium, little data are provided as to cost of production. However, production costs must be high because of the low efficiency of mining, dressing, and fabricating facilities. Because of decreasing ore quality as well as a transition to underground mining, costs are expected to rise sharply in the future.

Values of production costs in the Soviet Union reflect administrative or political prioritization structures rather than relative scarcity and the availability of land, capital, and labor. This makes meaningful cost comparisons between the U.S.S.R. and a market economy state a difficult problem.

MINING LAW OF THE U.S.S.R.

The mining law of the U.S.S.R. was drafted and approved in 1927 and implemented the following year. This was during the first decade of Soviet power, a period when a capitalist economy was left largely intact under a program known as the New Economic Policy which ran most of the mineral industries in the U.S.S.R. until 1928-29. Most of the provisions in the original mining law addressed themselves to the regulation of the private sector and have been left unaltered, but the law has been substantially changed through the years through the addition of decrees, and acts abolishing the private sector and regulating the administration of mineral resources. This has led to an unsystematized and seemingly nonhomogeneous body of laws, amendments, and regulations, concerning administration of mineral resources, defining the rights of State-owned mineral entities, and regulation of exploration and exploitation of mineral deposits. The issue of systematizing the mining law has reportedly been the subject of discussion and study at the level of the Supreme Soviet of the U.S.S.R.

MINERAL INDUSTRY LABOR

The low efficiency of labor is a problem endemic to the entire Soviet economy. The bureaucratization of the economy has led to high underemployment. Low productivity is due, in part, to management's hoarding or packing of personnel to justify greater annual allocations of capital to meet planned targets during production breakdowns or periods when there are substantial demands for the use of industrial workers for harvesting and other services. Added to a declining birthrate, this situation has led to a labor shortage in the U.S.S.R.

The declining growth rate in the industrial labor force

as well as declines in the growth rate of productivity, have resulted in an actual production drop in the fuels and metallurgical sectors of the economy, including the chromium industry.

Some measures that have been adopted in recent years to improve the labor shortage problem include the use of foreign labor from other CMEA member nations and mandatory overtime in mining.

CHAPTER 7.—CONCLUSIONS

Explored, exploitable chromite reserves of the Soviet Union are estimated at 229 million mt, placing the country third in world rank after the Republic of South Africa and Zimbabwe. Soviet chromite reserves are located in 26 deposits in Kazakhstan and the Urals and are considered sufficient to assure adequate supply for the long-term requirements of the Soviet Union, despite declining ore grades and depletion of high-grade resources amenable to surface mining.

The decline of chromite production and increased consumption by the U.S.S.R. and CMEA countries resulted in a decline of chromite exports to market economy countries. The 1966-77 peak of chromite exports is not expected to be repeated, and future exports will also likely emphasize ferrochromium rather than chromite.

Soviet exports of chromium materials to CMEA countries, which presently represent the bulk of total exports, are governed by the complex problems of regional supply-demand relationships within this group of countries, and are expected to continued at levels necessary to insure the trading partner country's demand levels. The principal factor in chromium material exports to market economy countries, as with other commodioty exports to these countries, is obtaining foreign exchange earnings, and the level of trade in chromium materials will thus be governed in part by Soviet needs for hard currency.

Although the U.S.S.R., is a net exporter of chromite, it does import chromium by way of substantial imports of stainless steel.

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